

Camera Control System

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Final Report

EE595

Electrical Design Project 2

Instructors: Dr. Steven Skinner and Tom McGuire

“I have read the entire report and it meets
my personal quality standards”

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Camera Control System

Abstract – This paper describes the design and technical specifications for a Camera Control System that helps a handicapped wheelchair user with limited use of his or her hands point a camera. Battery powered motors and a joystick control the pointing of a camera in two axes. Large, three-axis motorized camera control systems are available, but this system is a relatively small unit that is designed to be mounted on a wheelchair.

INTRODUCTION

This project came about as a result of meeting between Shari Rose, a resident at the Cerebral Palsy Research Foundation in Sedgwick County, Kansas and the authors, who are engineering students at Wichita State University. Shari, who uses a wheelchair, stated that she had trouble using her single lens reflex camera, because she has limited use of her hands.

The Camera Control System provides motorized, mechanical movement of an attached camera about two axes; rotation about the vertical axis (pan), and rotation about the transverse axis (tilt). The motions are controlled by a joystick. The joystick provides user input that is converted into motor commands via an Arduino digital controller. Limited (90 degrees) rotation about the longitudinal axis (axis of the lens) is available by manual means.



Constraints

Our client wanted a fairly large range of pitch movement (we set it to 45 degrees down and 70 degrees up), and a complete 360 degree pan. She also requested provisions for quick disconnect of the camera, and the ability to move it from landscape to portrait orientation. The system should be compact and self-contained, and mount easily to her wheelchair. It should be capable of working with a camera and lens that weigh 720 grams.

Standards

As a potential commercial product, we tried to stick to commercial-off-the-shelf (COTS) components. As a self-contained product, no industry communications standards were needed. To be successfully commercialized, the product would have to meet Underwriter Labs (UL) safety standards.

- The camera mounting screw is a standard ¼-20 machine screw that is used by all cameras sold in the USA.
- The battery charger is a standard 11.1 volt lithium-polymer balanced battery charger.
- The continuous motion servo size is Standard size.

Specifications

	Min			Max		
Case	Current (mA)	Voltage (V)	Power (mW)	Current (mA)	Voltage (V)	Power (mW)
No load	70	11.5	805	180	11.5	2070
Full load (1.8 lb)	70	11.5	805	240	11.5	2760

	Min	Max
Battery No Load Discharge Time	21 Hrs	8 Hrs
Battery Full Load Discharge Time	21 Hrs	6 Hrs
Battery Charge Time	2.5 Hrs	

Items	Dimensions	Weight	Type / Material	Operating range
Zippy Lipo Battery (11.1 V, 1500mAh)	100x34x18mm	138g	3 cell, 25C	
Servo (HS-311)	53x20x41mm	43 g	Continuous servo	4.8 V -6V
Motor (Servocity 1RPM)	37x37x76mm	142g	Torque: 2995 oz-in	3V-12V
Arduino Uno	75x54mm	28g		6V-20V
Joystick (2-axis)		5g		
Quick release mount				Max load: 9lb
PCB Board	80x60mm			
Box	Refer to drawings		Acrylic Plastic	
Aluminum Parts	Refer to drawings			

User Manual:

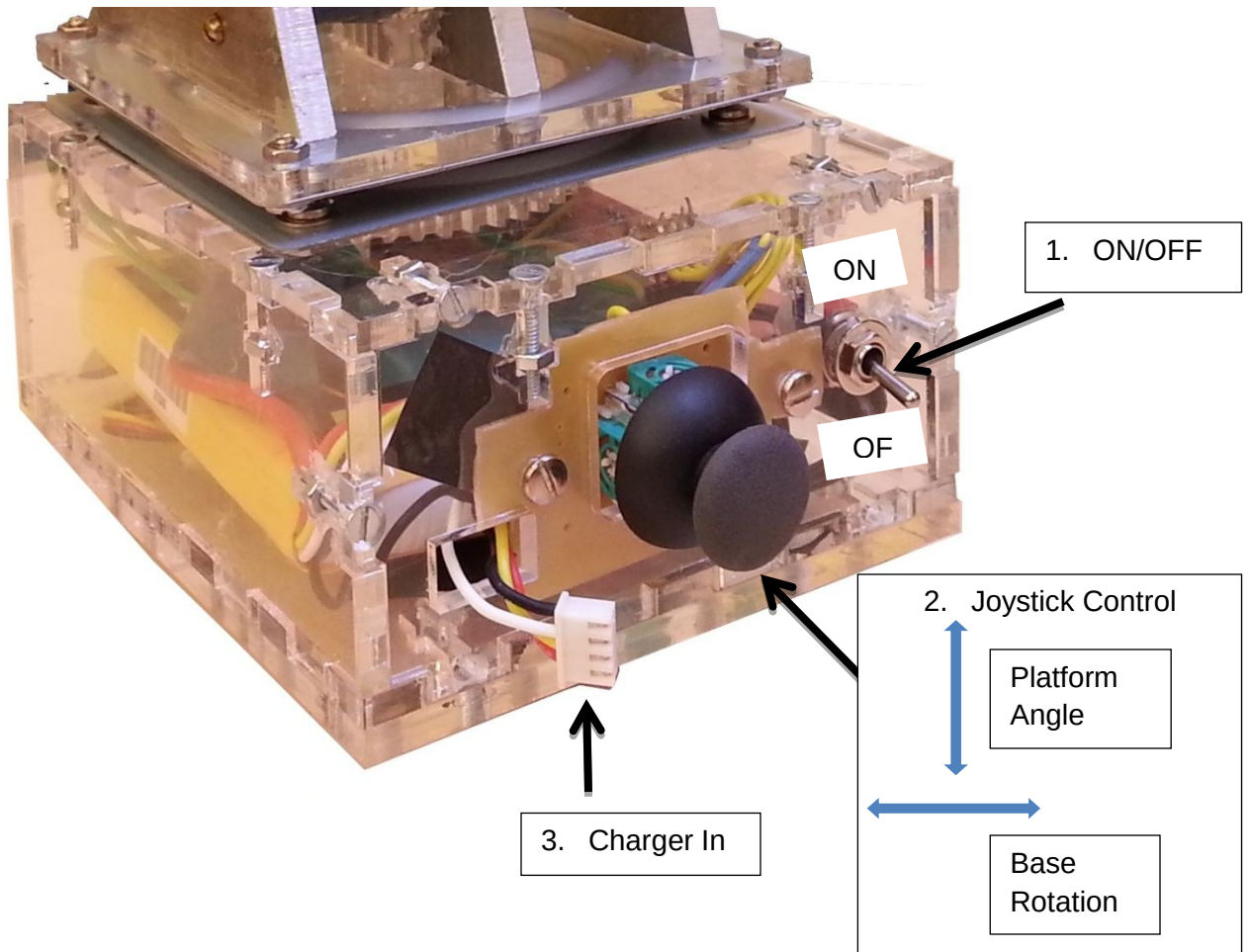


Fig. 1

Instructions on using the product:

1. The product can be powered on when needed using the switch as shown in Fig.1, part 1.
2. The joystick is used to control and align the position of the camera which mounted on the moving platforms. As shown in Fig.1, part 2.

- a. The two-axis joystick is used to rotate the platform clock-wise or anti-clockwise by moving the joystick right or left
 - b. The angle alignment can be controlled for up or down movement by moving the joystick up or down.
3. The rechargeable battery present inside the control box can be charged using the provided charger as shown below:

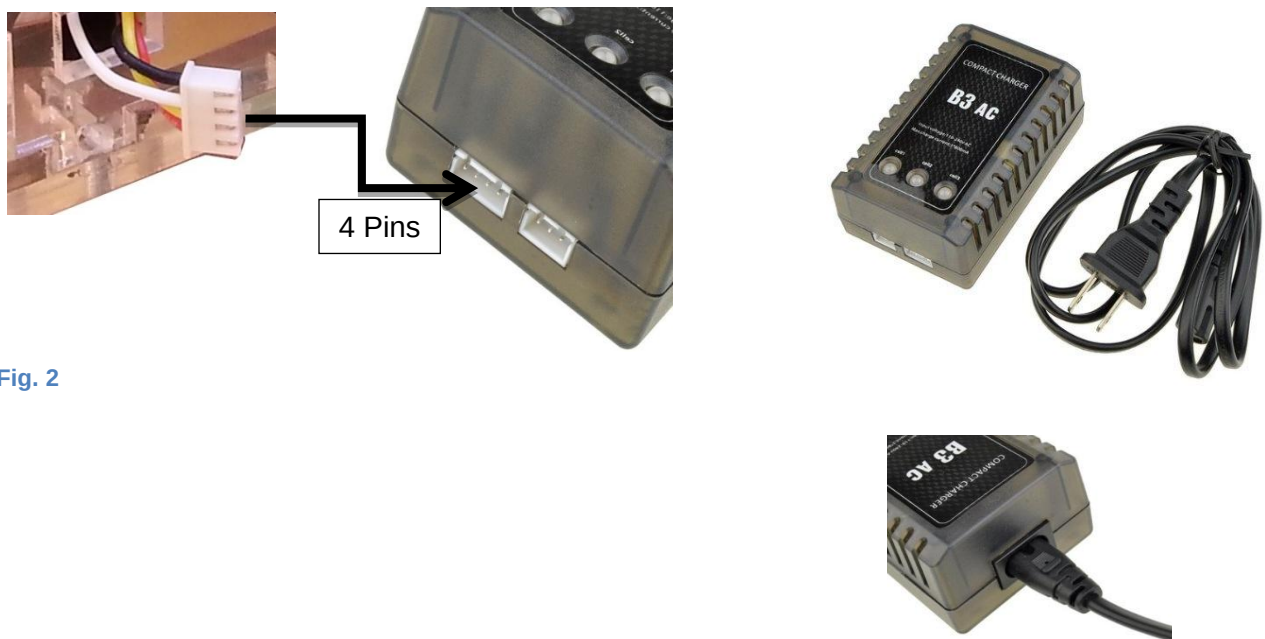


Fig. 2

WARNING: DO NOT STALL THE GEAR MOTOR BY STOPPING IT AGAINST THE SUPPORTS

Theory of Operation

The product is powered from an 11.1 V rechargeable lithium polymer battery which is connected to the power switch. When the switch is on, Arduino Uno board gets the input voltage of 11.1 V. Arduino board regulates the 5V supply and 11.1V supply to the circuit board. When the joystick is moved left or right, the analog value of the potentiometer is read by the arduino board and sends the signal to the servo motor for clockwise or counter-clockwise rotation. Servo motor is also powered by the 5V supply from the circuit board. When the joystick is moved up or down, the analog value of the potentiometer is read by the arduino board and the signal is sent to the two inputs of L272 amplifier in the circuit board. The amplifier is powered with the 11.1 V supply from the board. The input supply to the motor is provided from the amplifier's output which triggers the motor to change its polarity and rotate in a desired direction.

Scenario of use:

People with disabilities with trouble in holding the camera and taking the pictures can use the product. The product can be easily mounted to the wheelchair or a tripod.

Walkthrough of typical operation:

The product is used to align and rotate the position of the camera so that the camera is stable and the weight of the camera is supported by the product. The user can manually take the snapshot.

Unique features of the product:

The product is designed to handle the weight of professional camera and lens up to 2.2 pounds. The product is cheaper in comparison to the products available in the market and it can be easily built using the parts available in the market. The camera can be positioned to take the pictures of the sky and ground and also take the pictures all around. The product is specifically built based on the need of specific client Shari Rose.

Benefits for the user:

People with disability will get a platform for using their camera to take nice quality pictures with the ability to control and align the camera.

Alternative solution:

One of the alternatives is to have someone help the person with disability to carry the camera or wait for longer time to allow the person to take the picture. Other alternative is to buy the similar products which are very expensive and is built for the professional filmmaker for video shooting purposes.

This product provides solution to the specific people with disabilities and the product can be mounted on wheelchair which aids the client to be independent and enjoy their passion of photography as a hobby or could be even used as the professional career.

Technical Description

Our product consists of a wheelchair mount, an enclosed box, a rotating platform, a tilting platform, and an adjustable camera mount.

The wheelchair mount uses a commercial wheelchair mounting clamp to hold the camera control system in a convenient position for the user. It is made from two steel tubes welded together a right angle, and a plastic platform. The platform is secured to the mounting tube assembly with conduit clamps, to allow angular adjustment of the base. The wheelchair mount is attached to the enclosed box with four screws.

The enclosed box is a clear acrylic plastic box that holds an electronics package, a continuous motion servo, a gear set, an on-off switch, and a joystick.

The electronics package consists of a battery, Arduino controller, and a circuit board. The battery is a commercially available 12 volt, 1500 milliamp rechargeable, lithium-polymer unit. It consists of three cells connected in series. The Arduino controller takes 4-bit commands from the joystick controller, and converts them into power commands for the servo and motor. These components are more fully described in the theory of operation.

The continuous motion servo is a commercially available (Hitech HS-311) unit that has been modified to run continuously. It has 48 inch-ounces of torque at 4.8 volts and runs at ~52 rpm at 4.8 volts.

The gear set consists of two laser-cut plastic gears approximately .25 thick. The smaller gear is attached to the servomotor shaft, and has 10 teeth. The larger gear is attached to the rotating platform, and has 40 teeth. Thus the gear set provides a speed reduction of 4:1 to the servomotor.

The joystick is a commercially available, 2-axis controller.

The rotating platform is fixed to the top of the base with a rotating ball bearing assembly. It has supports for the tilting platform, a shaft that mates with the first (4:1) gear set, and a motor that moves the tilting platform through a second gear set.

The rotating ball bearing assembly is a lazy susan turntable with a four inch by four inch rectangular base, and a 2-3/16 inch diameter hole through its' center.

There are three tilt platform supports that are screwed to the rotating platform base, and provide room for the tilt platform movement, in addition to mounting spot for the tilt motor. A hole at the top of each support is used to hold the geared shaft that connects the rotating platform to the tilt platform.

The tilt electric motor is a 12 volt, one revolution per minute gear motor that provides 2,995 inch-ounces of torque. This high torque is needed to hold the tilt platform, camera mount, and camera in place when the motor is de-energized.

The motor gear is a 32 tooth brass gear with a 1.00 inch pitch diameter. It is secured to the six millimeter motor shaft with a set screw.

The tilting platform holds the camera mounting system, and connects to the tilting platform with a geared shaft that meshes with the motor gear.

The tilt platform is attached to the rotating platform with three blocks that are drilled to hold the geared shaft securely with set screws to the geared shaft. The tilt platform rotates about the axis formed by the geared shaft. The gear on the tilt shaft is identical to the gear on the motor, so the gear ratio is 1:1.

The camera mounting system is a commercial product that we slightly modified. We replaced a small lever that locks the camera mount ball with a larger one that is easier for a handicapped person to move. This system provides a quick release for the camera by means of a separate base that attaches to the camera through the mounting screw hole. It also gives a means of switching the camera from landscape to portrait orientation.

Schematics:

Circuit Board Design:

Circuit board designed using “Eagle” circuit board designing program as shown in Fig.3 with the connection to the servo, motor, power supply and joystick

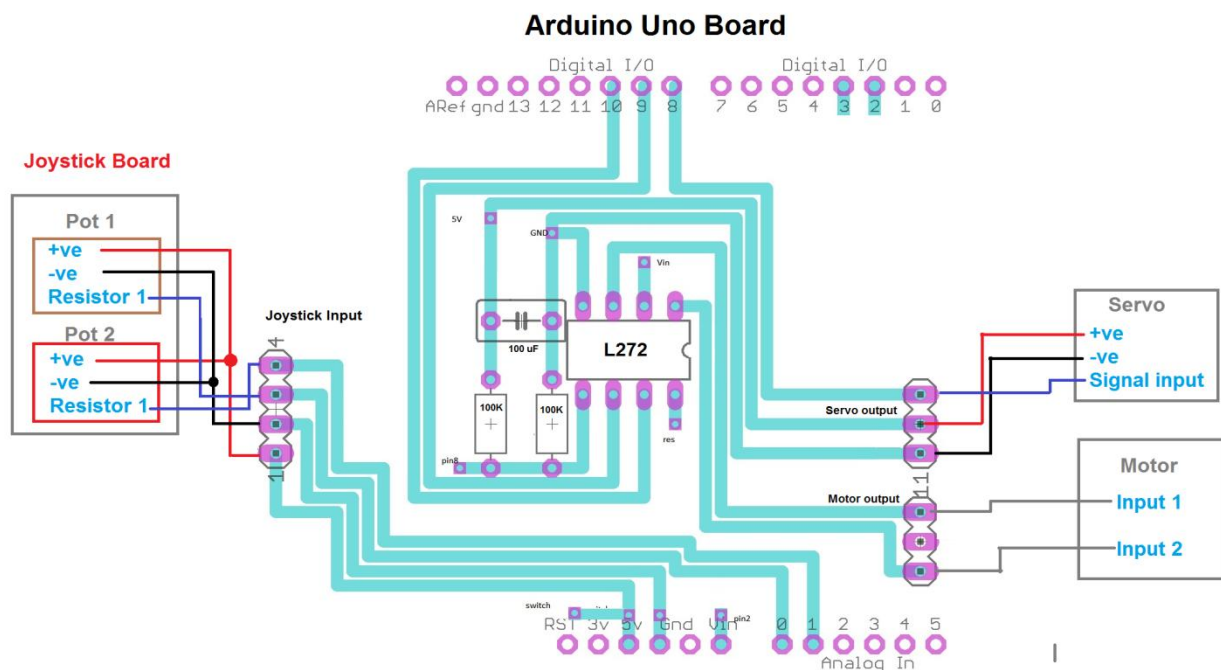


Fig. 3

Arduino Board Program:

Arduino code was written using the arduino compiler “Sketch” and uploaded to the Arduino via USB cable.

- A program flowchart is in Appendix A
- A code listing is in Appendix B

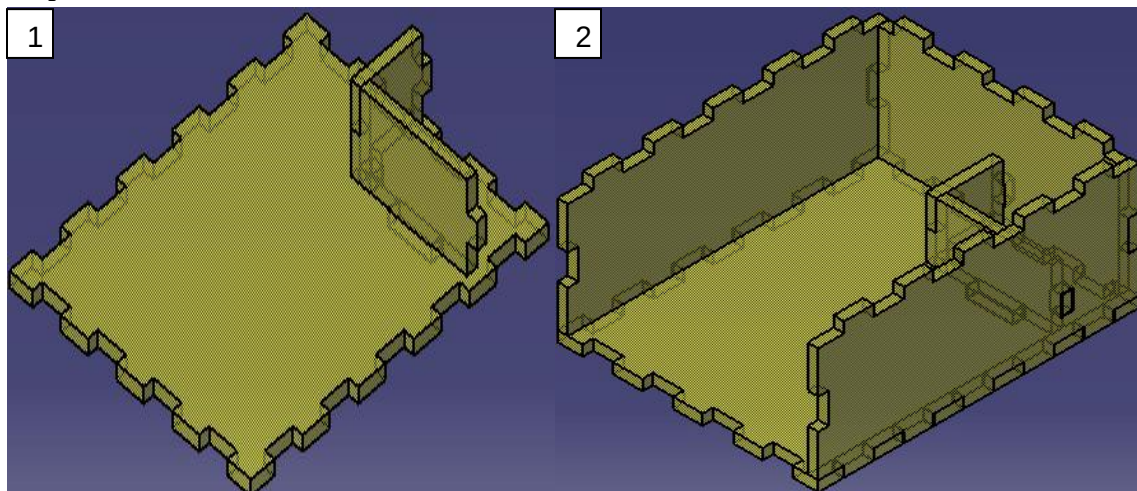
Structural and Mechanical Design:

- An indented parts list is in Appendix C at the end of the report.
- Drawings of the mechanical parts are in Appendix D

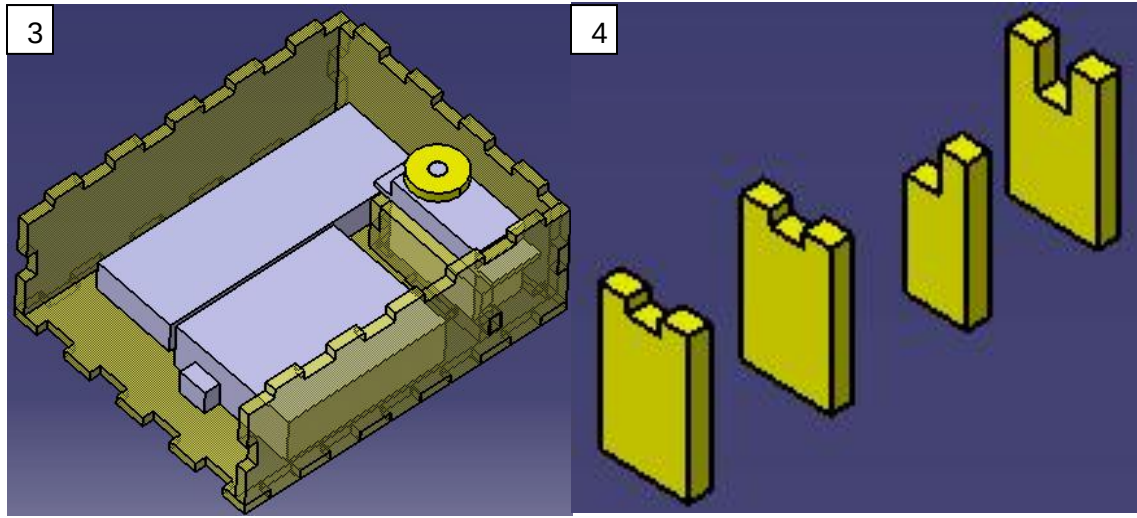
Assembly of the camera stand:

Step 1: walls containing the servo assembled on the bottom platform of the control box.

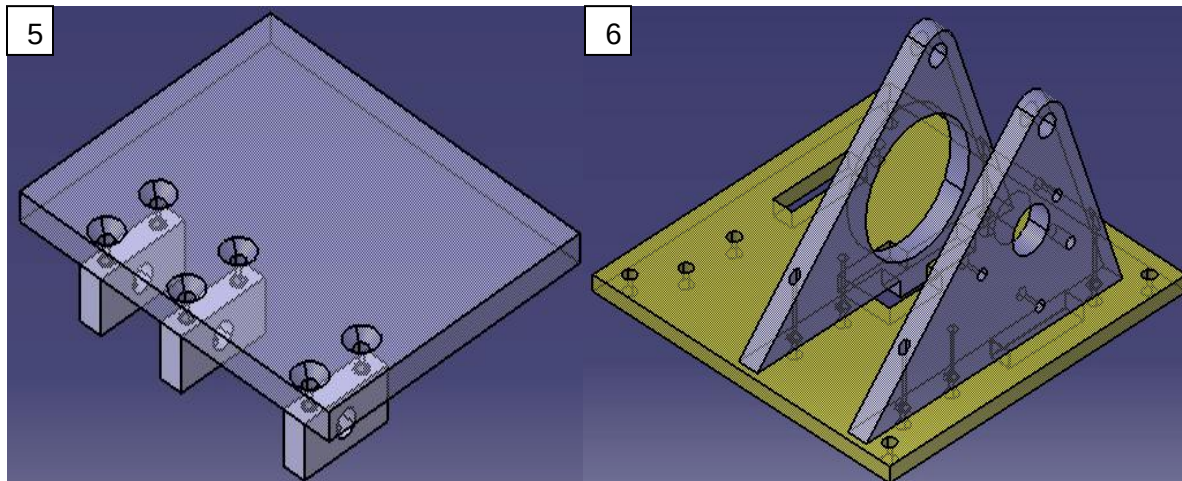
Step 2: three sides of the control box assembled.



Step 3: battery, servo and main electrical set (arduino & circuit board) are placed in the box.
Step 4: the 4 pieces that make rotating shaft are glued together.

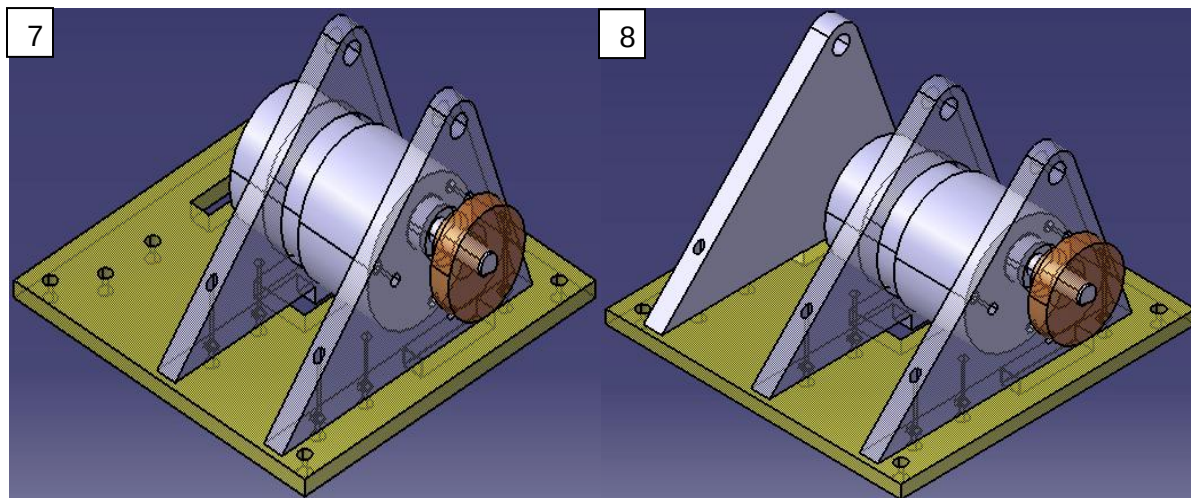


Step 5: aluminum pieces that will contain the pitch shaft are connected to the pitch platform
Step 6: screw two triangular aluminum pieces to the top of the rotating platform



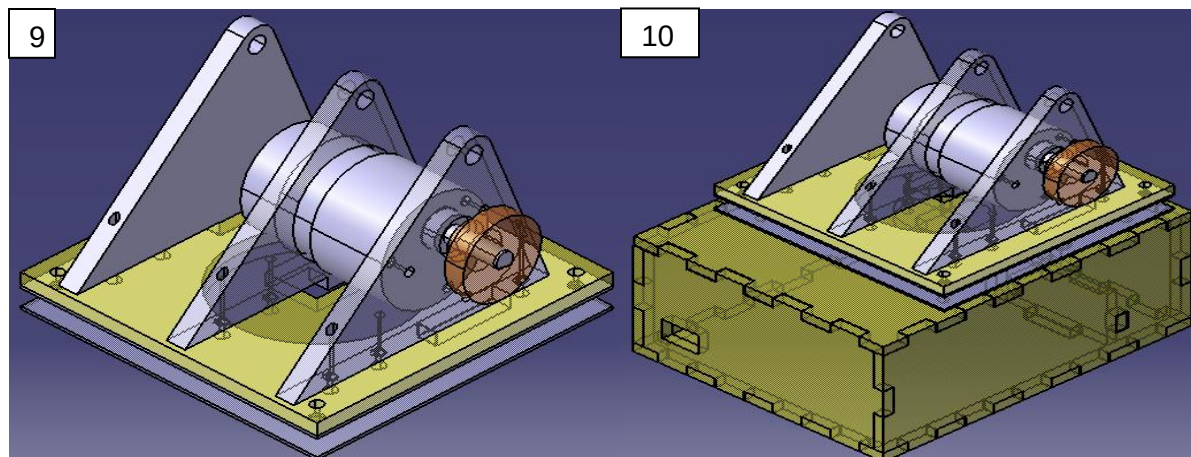
Step 7: fix the motor in position and fix the gear to motor's shaft

Step 8: place the third triangular piece on top of the rotating platform



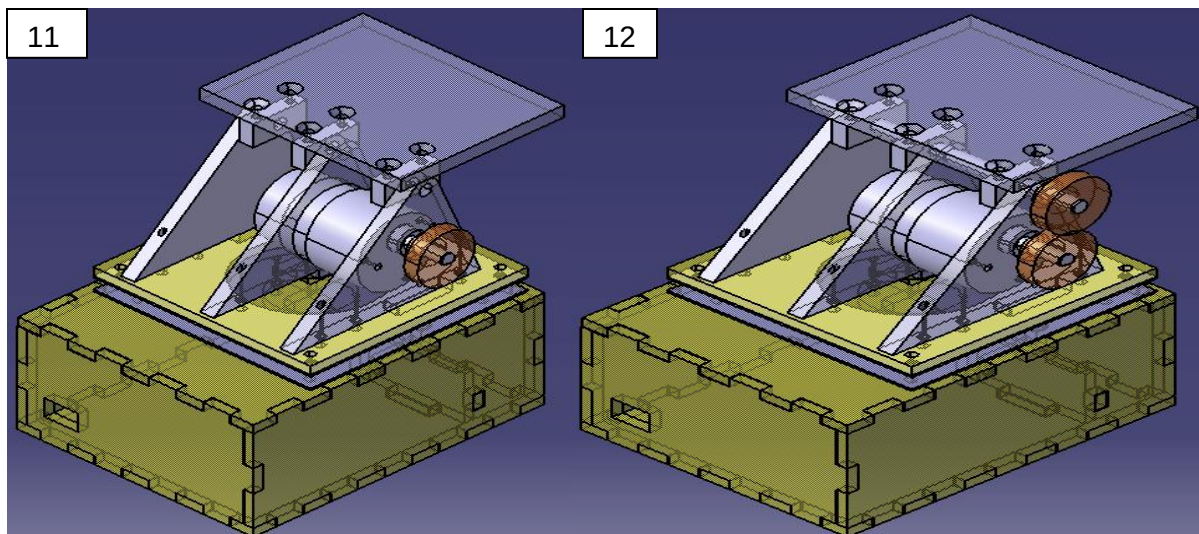
Step 9: fix the top rotating platform to the turntable with screws and nuts

Step 10: fix the bottom of the turntable to the top of the control box with screws and nuts



Step 11: align the pitch platform with the triangular pieces

Step 12: insert the pitch shaft with gear to connect triangular pieces with pitch platform



Purchased Parts List:

Qty	Part Description	Manufacture	Part Number	Supplier	Price/Unit
1	Arduino	Arduino	Uno	WSU	\$ -
2	Acrylic Plastic			Aluminum Yard Store	\$ 11.50
1	Aluminum Sheet			Aluminum Yard Store	\$ 26.50
1	Servo	Servocity	HS-311	servocity.com	\$ 7.99
1	Motor	Servocity	RZ12-3000-1RPM	servocity.com	\$ 24.99
2	Gear	Servocity	615270	servocity.com	\$ 12.99
1	Turntable	Shepherd	9547	ACE Hardwar Store	\$ 4.99
1	Battery	Zippy	Z15003S20C	Hobbyking.com	\$ 9.39
1	Charger	Newer	40061517	Amazon.com	\$ 12.10
1	Miscellaneous				\$ 15.00
				Total	\$ 149.94

Usability Study

Usability Study – Meeting 1
Date – Nov 14, 2013
Participants - Saeed Alsaleeb
Bill Drescher
Kusay Kharmandh
Rupak Poudel
Shari Rose
Participants were the design team and the project client.
Training - Product demonstration and verbal instruction.
Evaluation - Observation and verbal responses.

Results – At this meeting, our main purpose was to test the mounting of the Camera Control System to the wheelchair and get Shari's comments. The mount we brought to the meeting was obviously way too long (high), so we discussed alternate designs. We mounted Shari's SLR camera on the device (on a table), to demo it, and discovered that the motor stop torque was insufficient to hold the camera tilt platform in place. (The motor had enough torque to move the camera, but after a certain angle was exceeded, the tilt platform continued to move when the motor was unpowered.) Shari observed that the joystick control lever was very short, and that a longer one might be easier to use.

Actions Taken – A new higher torque motor was ordered and installed. The new motor has 2,995 in.-oz. of torque compared to the old motor's 613 in.-oz. of torque. It is also slower; 1 RPM vs. 6 RPM. Two possible new mounts were designed and drawn, and transmitted to Greg Carpenter at the CPRF machine shop for his evaluation and construction. Greg decided to build the mount that consisted of two tubes ~.75 inch in diameter, welded together at a right angle. A new longer (3") joystick lever was designed and 3D printed on the Thing-O-Matic.

Usability Study – Meeting 2
Date – Nov 19, 2013
Participants - Saeed Alsaleeb
Bill Drescher
Kusay Kharmandh
Rupak Poudel
Shari Rose
Participants were the design team and the project client.
Training - Product demonstration and verbal instruction.
Evaluation - Observation and verbal responses.

Results – Again at this meeting, our main purpose was to test the new mounting of the Camera Control System to the wheelchair and get Shari's comments. Trying the new mount, two problems were apparent. One problem was that putting the down-tube of the mount into an open, vertical tube of Shari's wheel chair resulted in the device rotating under the influence of gravity. The second problem was that the mount still positioned the camera too high for comfortable use.

The new motor now held the camera tilt platform in position when the motor was unpowered. Shari was OK with the slower tilt motion of the camera, and stated that she might prefer the slower speed, as it would allow more accurate pointing of the camera. Shari observed that the camera mount locking lever that to be thrown to allow the camera to be switched from landscape to portrait orientation was small, and difficult for her to operate. She didn't like the idea we proposed to mount the joystick controller separately, and connect it to the main box via wires. Shari asked if we could mount the joystick onto the main box. After some discussion it was decided to mount the controller on the back of the box, and that the old, smaller lever would be preferable in this position. The quick disconnect feature of the camera mount was tested, and Shari considered it to be acceptable.

Actions Taken – Tom McGuire had provided us with a wheelchair tube mounting clamp earlier in the semester to try, but we thought we knew better. This was located, dusted off, and found to fit the Camera Control System mounting tube. A new, longer camera mount locking lever was designed and 3D printed on the Thing-O-Matic. New holes were cut in the back of the box and the old, smaller joystick control lever was attached. (It didn't come up in the usability testing with the client, but at this time we realized that the electrical power circuit didn't have an on-off switch. A small toggle switch was added to the power circuit and mounted to the back of the box. Labels reading "ON" and "OFF" were printed and added to the box.)

Usability Study –	Meeting 3
Date –	Nov 21, 2013
Participants -	Saeed Alsaleeb Bill Drescher Kusay Kharmandh Rupak Poudel Shari Rose Participants were the design team and the project client.
Training -	Product demonstration and verbal instruction.
Evaluation -	Observation and verbal responses.

Results – The wheelchair tube mounting clamp fit and allowed us to mount the device lower on the tube. The resulting height was judged to be 'perfect', and the device is securely positioned and no longer moves under the influence of gravity. The side of the clamp that holds the device is lever actuated, and Shari can use it to remove the camera control system herself. The clamp can be positioned so that Shari can still use the loop of the tube it is clamped to. Unfortunately, the side of the clamp attached to the wheelchair is secured with bolts, and takes tools to remove. The new camera mount locking lever was considered to be acceptable, but a longer length would be better. However, a longer lever would hit the camera body when the camera is moved to the portrait position. Shari was very pleased with the positions of the joystick control lever and on-off power switch.

Final Product Survey

Date: Monday, December 09, 2013

1. Is it easy to move the joystick?

It is very easy.

2. Is the input given to the joystick and the movement of the camera as predicted?

Yes, it is as predicted.

3. How much will you be willing to pay for the product like this?

\$150 - \$200

4. Are you able to mount the camera control system easily on the wheelchair?

No, require help and tools.

5. Are you able to mount and release the camera easily from the system?

Yes, I am

6. Overall, was the product effective in assisting you to take pictures?

Yes, love the product and looking forward to use it.



Shari Rose testing the final Prototype at CPRF

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Historical Perspective

The idea for our project came from a meeting at the Cerebral Palsy Research Foundation (CPRF), where one of the residents expressed a desire for a way to control the pointing of her single lens reflex (SLR) camera. A web search revealed that there are commercially available motorized camera mounts, but they seem to be aimed at professional or serious amateur film makers. The available camera mounts are large and have 360 degree motion on three axes. They do not appear to be suitable for someone confined to a wheelchair to use.

We decided to try to make a much smaller and lighter device. We felt that motorized control of two axes would be sufficient for still photography, and that complete 360 degree pitch motion was unnecessary.

Our first prototype was constructed mostly from wood, and motion was provided by two servos using pushrods. It was too big for mounting on a wheelchair, and did not provide the accuracy we wanted but seemed to be a step in the right direction. The motion provided by a servo (approximately +/- 15 degrees) was too small for the pan axis. See Fig. 4.

Then we worked on improving our second prototype depending on the feedback we received from our client and many people we had met during the open house. We improved the first prototype by exchanging the wood plates for a plastic box. The rotation motion was changed from a pushrod to a gear set driven by a continuous motion servo. This project was powered directly from an external power supply using a USB cable. Tilt motion was still provided by a pushrod. See fig 5.

Feedback from our client indicated that a larger range of pitch motion was needed. For the third prototype, we replaced the up and down movement servo to a motor providing 2,995 in.-oz. of torque at 1 RPM. This high torque is needed to hold the camera in place against the camera's weight. We powered the project with a rechargeable battery.



Fig. 4 Prototype I under construction

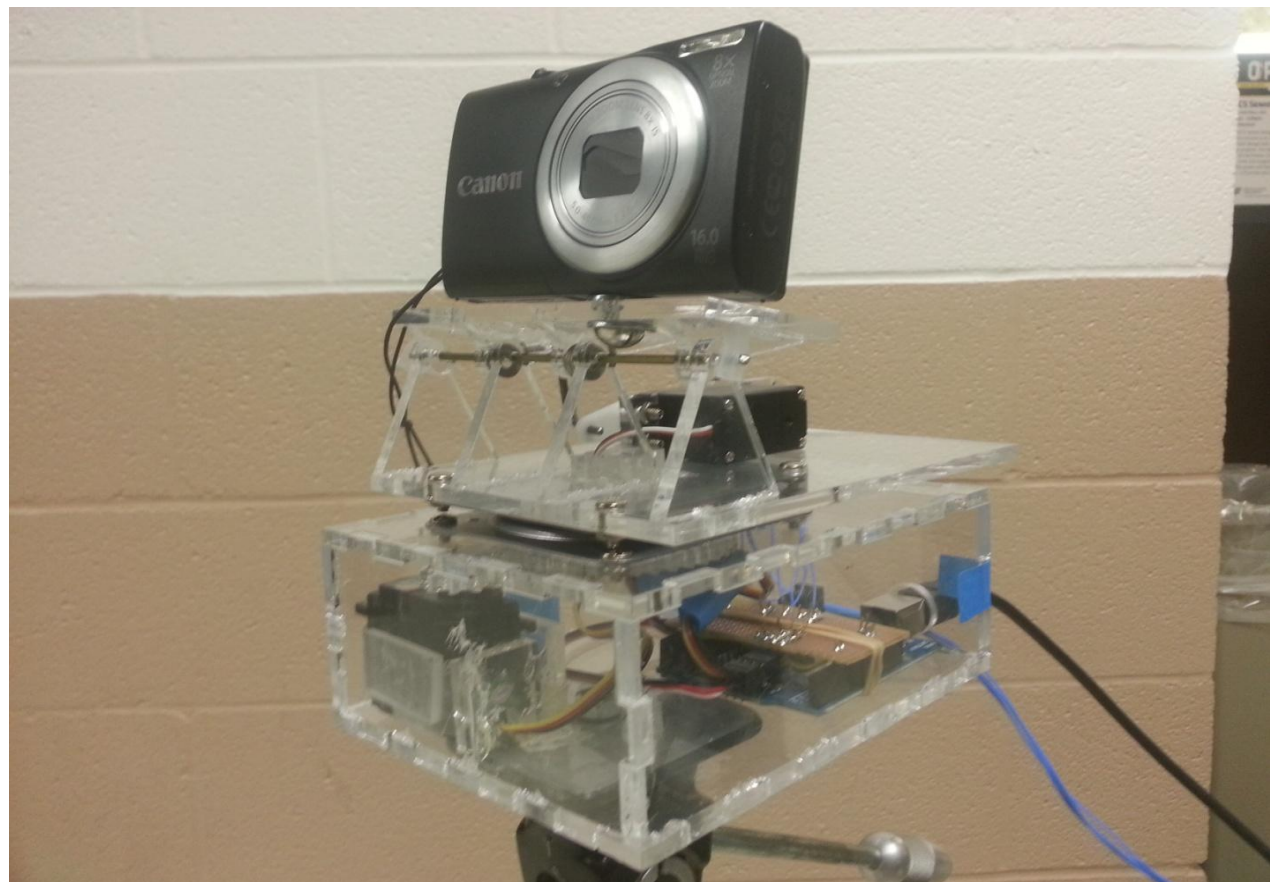


Fig 5 Prototype II

Business Viability

The project created by the Senior Design Project was a camera control system for a wheelchair, which was designed for our client, Shari Rose. The wheelchair holds a rotating platform that tilts and adjusts in size; this is the base where the camera is placed. The project was purposely designed to help any person with cerebral palsy or other diseases that limit the person to a wheelchair and limits their hand mobility, to use a camera.

Our client usually uses a Single Lens Reflex camera but due to limited use of her hands that she suffered from like most patients with her disability, she had a lot of difficulties whenever she attempted to use her camera. The task was to find a method of holding a camera for the client and for patients in general who suffer from the same disability, the goal was to make her be capable of aiming her camera, and snap photos, with limited use of the hands.

The client wanted a fairly large range of pitch movement, as it made photography more accessible from the chair. The angles of the mount were set to 45 degrees down and 70 degrees up. A complete pan of 360 was possible from the mount. Ms. Rose also requested provisions for quick detachment of the camera. In addition, the ability to move it from landscape to portrait orientation, amongst other modes of photography, is something that she requested and that the team thought made perfect sense. The device is compact and self-contained; it's vital that it mounts easily and firmly to the wheelchair. And the weight of the camera and lens should be contained when it weights 720 grams.

The capability of selling such device depends on two aspects:

1. The number of camera users that were confined to a wheelchair after their interest in photography was a part of their life or a career that they chose to themselves.
2. People whom were already confined to their wheelchairs when their interest in photography was stimulated, but they felt that their wheelchair was a detriment to their abilities to participate in the hobby or the business of photography.

With the right amount of marketing, the target audience can and will feel that the product is not an attempt to make profit off of their disability but really it's a product that will give them their ability to become photographers again, or create a new option for those who've always been confined to the chair but developed the interest later in life.

Considering the market which will exist for both the general criteria stated above, and the interest in professional photography is on the rise, then it seems like a viable option to actually develop the product. The product, despite being a privilege rather than a right, could be covered by insurance and disability services.

Another market that could fit the product is that of mental health services and care. In a higher percentage than in normal cases, wheelchairs users experience a few mental disorders; depression and anxiety being two of the most major. Photography could be the medicine to these issues.

Future Work

Future development – Before we deliver our project to our client, we intend to add two limit switches to the tilt platform to prevent it from contacting the supports and stalling the tilt-motion motor. The motor with its' integral plastic gear train, is quite powerful (2,995 in-oz. or over 15.5 lb-ft of torque). If it is stalled, it is capable of shredding the final gears in the gear train. In fact, we believe this is what happened just before our display at Exploration Place. Some safety improvements would need to be made before the project could be released commercially. Specifically, the tilt platform gears should be covered and the pinch injury potential between the tilt platform and its' supports needs to be evaluated.

Redesign – The camera mount is a commercially available piece that provides manual, three-axis motion and quick disconnect for the camera. The quick disconnect is needed by our client, and the ability to rotate the camera from a landscape orientation to a portrait orientation was also requested. The part we purchased has the capability needed, but the three-axis freedom is over-kill. The camera mount also moves the camera up several inches, affecting the mounting system. This raising of the camera also affected the stop-position holding of the tilt platform, requiring us to go with the highest torque (and thus slowest) motor we could buy. A much simpler and lower profile camera mount, with quick disconnect and only one-axis motion would be very useful.

The project we produced is obviously a prototype, made with the tools and materials that were available to us in the senior-design lab. We're not manufacturing engineers, but it seems plausible that design for manufacturing could reduce the part count and simplify the assembly of the device. Injection molding might offer great manufacturing cost savings in large scale production.

The control program we are using is quite simple, and the full Arduino processor may be over-kill. A custom integrated circuit could provide adequate functionality and savings in size and power requirements.

Added functionality – Based on the comments of our client, it seems that we hit the spot of meeting her requirements and desires.

Unneeded complexity – The rotating platform of the device is capable of continuous 360 degree rotation. This could lead to problems with excessive twisting of the motor power wires. It may be possible to control this through programming.

EECS Senior Design Fall 2013

Project Contract

CAMERA CONTROL SYSTEM FOR WHEELCHAIR

Team Name: Team 6 (3!)

Team Members: Saeed Alsaleeb, William Drescher, Ahmad Kusay Kharmandh, Rupak Poudel

The product we are working on is to build a control system for the wheelchair clients to assist them in using their camera. People with disabilities often have difficulty in holding the camera steady. We are working for a client at CPRF, Shari Rose. We are making the product to mount on her wheelchair which can be easily controlled with joystick. The name of her camera that we will be working on is *E-620 Olympus. One of the lenses is 14-42 mm ZUKO lens.*

Functions and Features of the product:

- **360 degree pan rotation on vertical axis**
- **-45 degree to +60 degree pitch rotation on horizontal axis**
- **Quick release mount for the camera**
- **Easy to mount the product on our client's wheelchair**
- **Battery powered product**

Our product will be tested by our client Shari Rose. We will go to CPRF and have her try the product and get the feedback from her. We will be asking the following questions for her feedback:

- 7. Was it easy to move the joystick?**
- 8. Was the input given to the joystick and the movement of the camera as predicted?**
- 9. How much will you be willing to pay for the product like this?**
- 10. Were you able to mount the camera control system easily on the wheelchair?**
- 11. Were you able to mount and release the camera easily from the system?**
- 12. Overall, was the product effective in assisting you to take pictures?**

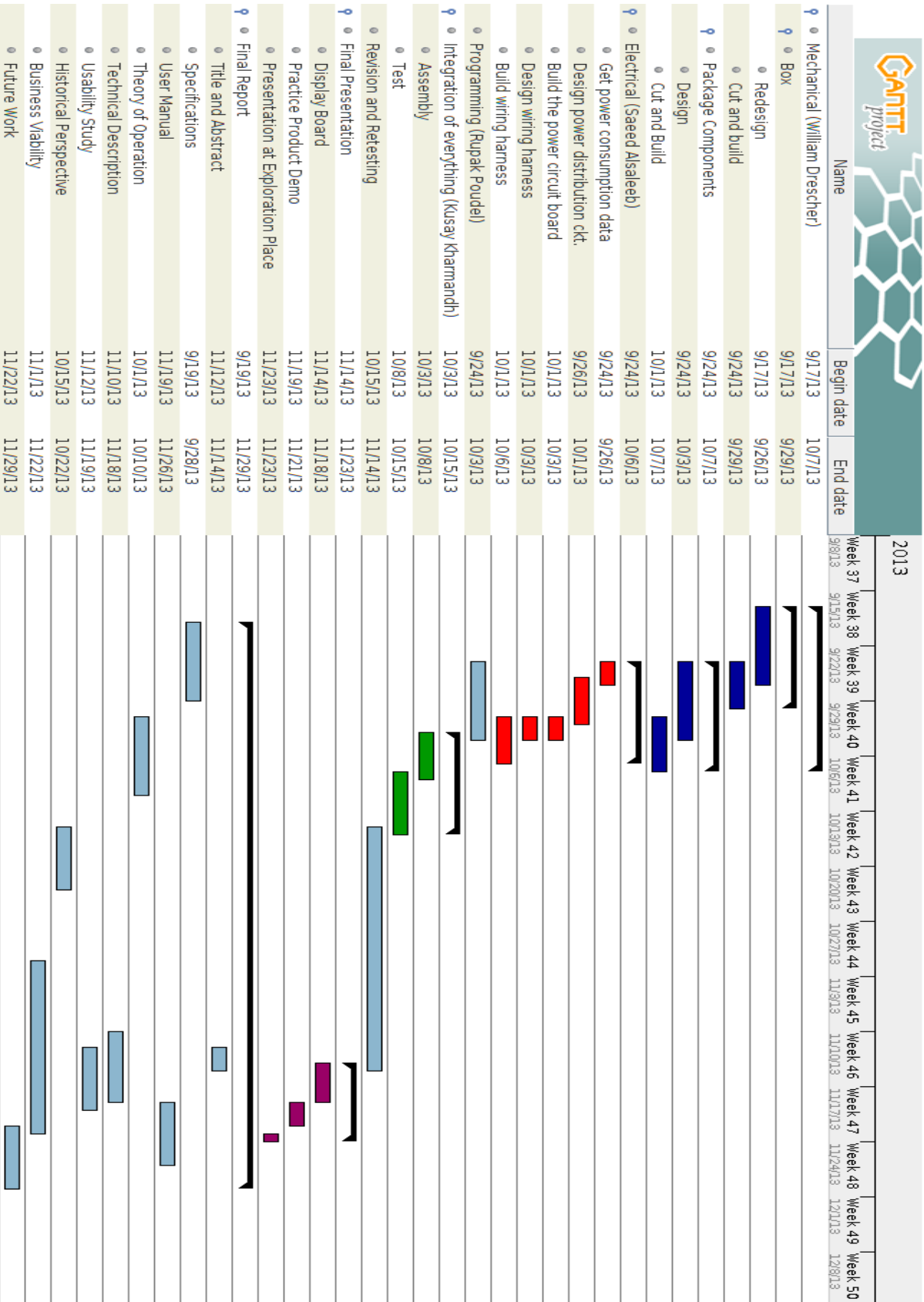
Saeed Alsaleeb

William Drescher

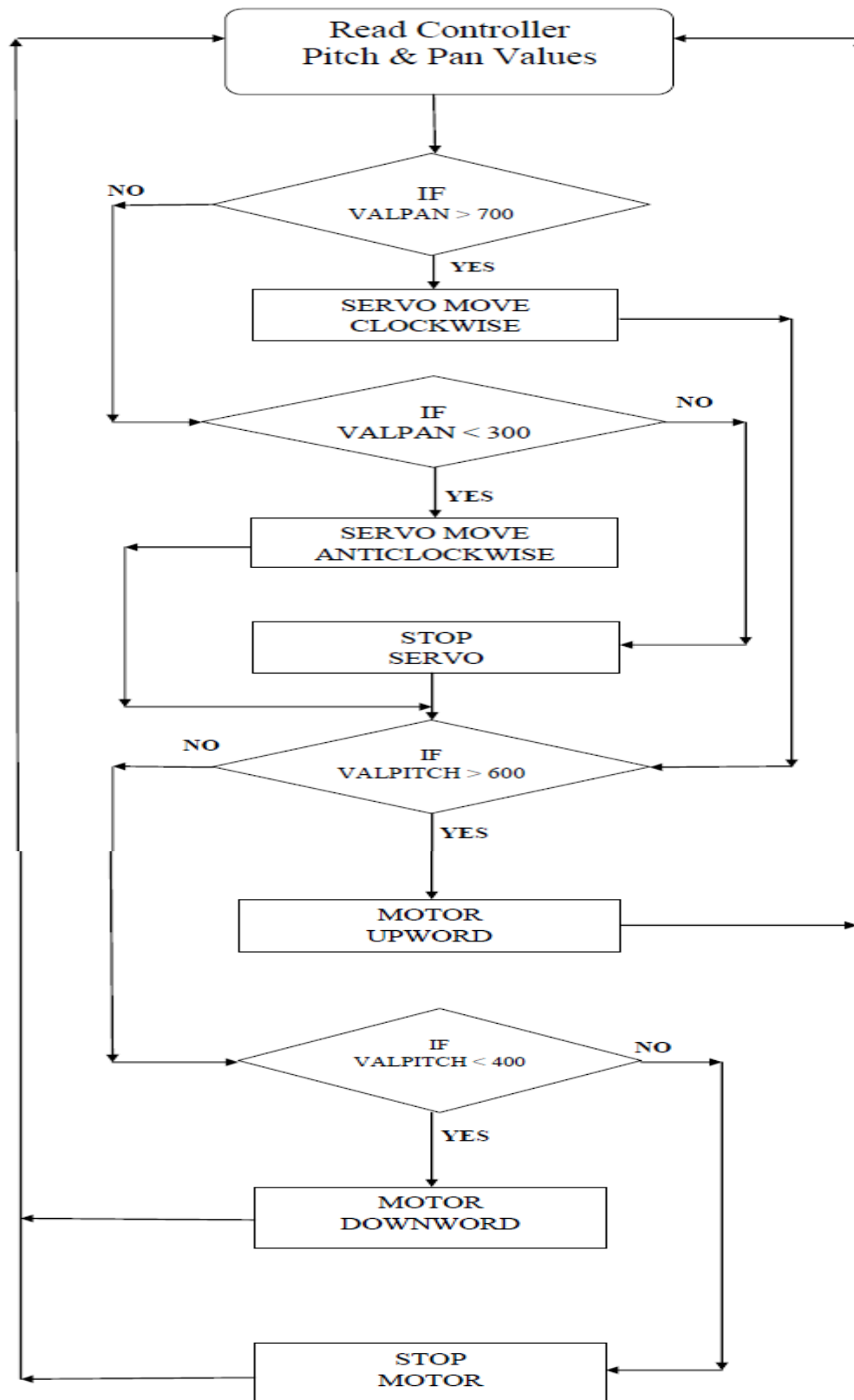
Kusay Kharmandh

Rupak Poudel

Schedule



Appendix A - Program Flow Chart



Appendix B – Arduino Code

```
#include <Servo.h> // header file for servo

Servo servoPan; // Create servo object for pan movement
int potPinPan=1; // Analog input from servoPan to arduino board
int valPotPan; // Variable to read resistance value from pin 9
const int analogPin = A0; // Assigning A0 pin to analogPin
int fadeValue;
int val = 500; // store anolg read from potentiometer for pitch movement
int motpin1 = 9; // Digital pin attached for motor input to amplifier
int motpin2 = 10; // Digital pin attached for motor input to amplifier

void setup() {
  servoPan.attach(8); // Attaching servoPan on pin 9
  servoPan.write (80); // Initially stopping the rotation of servoPan
  pinMode (motpin1, OUTPUT); // output to amplifier input
  pinMode (motpin2, OUTPUT); // output to amplifier input
}

void loop() {

  valPotPan = analogRead (potPinPan); // reads value from the potentiometer for pan
  val = analogRead(analogPin); // reads value from the potentiometer for pitch

  if (valPotPan>700) {
    servoPan.attach(8);
    servoPan.write (180); // rotate servoPan
  }
  else if (valPotPan<300) {
    servoPan.attach(8);
    servoPan.write (0); // rotate servoPan
  }
  else {
    servoPan.detach(); // Stop the servo movement
  }

  if (val>600){ // Pitch movement up
    analogWrite(motpin1, 255);
    analogWrite(motpin2, 0);
    val = analogRead(analogPin);
    delay(1);
  }
  else if (val<400){ // Pitch movement down
    analogWrite(motpin1, 0);
    analogWrite(motpin2, 255);
    val = analogRead(analogPin);
    delay(1);
  }
  else {
    analogWrite(motpin1, 255);
    analogWrite(motpin2, 255);
    val = analogRead(analogPin);
    delay(1); } }
```

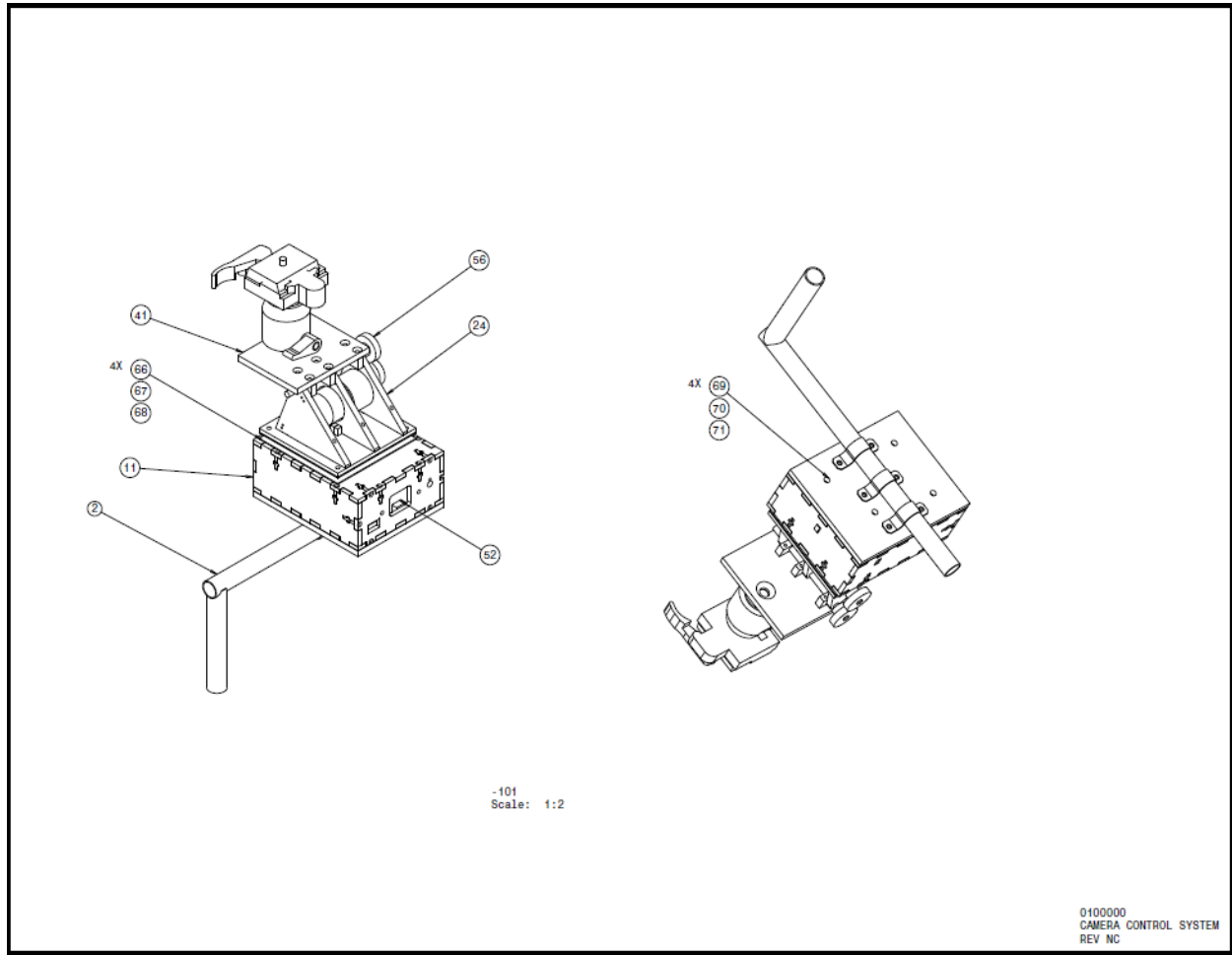
Appendix C – Indented Parts List

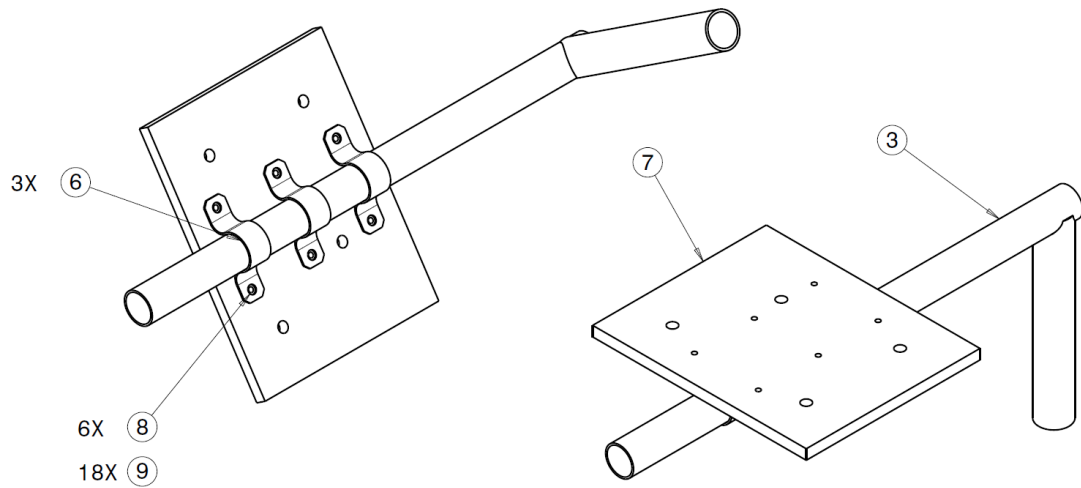
INDENTED PARTS LIST

PART NUMBER	NOMENCLATURE	QTY	FIND #	MAT'L	SOURCE
0100000-101	ASSEMBLY	1	1		MFG
0101000-101	MOUNTING ASSEMBLY	1	2		MFG
0101001-101	MOUNTING TUBE WELDMENT	1	3		MFG
0101001-201	VERTICAL TUBE	1	4	STEEL	COML
0101001-203	HORIZONTAL TUBE	1	5	STEEL	COML
0101002-101	CONDUIT CLAMP	3	6	STEEL	COML
0101003-101	MOUNTING PLATFORM	1	7	ACRYLIC	MFG
N/A	6-32 X .375 SCREW	6	8	STEEL	COML
N/A	NO. 6 WASHER	18	9	STEEL	COML
0102000-101	ENCLOSURE ASSY	1	10		MFG
0102001-101	BOTTOM PANEL	1	11	ACRYLIC	MFG
0102002-101	BACK PANEL	1	12	ACRYLIC	MFG
0102003-101	FRONT PANEL	1	13	ACRYLIC	MFG
0102004-101	LEFT PANEL	1	14	ACRYLIC	MFG
0102005-101	RIGHT PANEL	1	15	ACRYLIC	MFG
0102006-101	TOP PANEL	1	16	ACRYLIC	MFG
0102007-101	SERVO PANEL	1	17	ACRYLIC	MFG
0102008-101	SERVO PANEL	1	18	ACRYLIC	MFG
N/A	4-40 X .75 FLATHEAD SCREW	16	19	STEEL	COML
N/A	4-40 NUT	16	20	STEEL	COML
0102009-101	SERVO SHIM	A/R	21	ACRYLIC	MFG
HS-311	SERVO MOTOR	1	22		Hi-Tech
0102010-101	GEAR, 10 TOOTH	1	23	ACRYLIC	MFG
0103000-101	ROTATING PLATFORM ASSY	1	24		MFG
N/A	BEARING	1	25		COML
N/A	6-32 X .375 FLATHEAD SCREW	4	26	STEEL	COML
N/A	6-32 NUT	4	27	STEEL	COML
N/A	NO. 6 WASHER	4	28	STEEL	COML
0103001-101	ROTATING PLATFORM	1	29	ALUMINUM	MFG
0103002-101	TILT PLATFORM SUPPORT	1	30	ALUMINUM	MFG
0103003-101	TILT PLATFORM SUPPORT	1	31	ALUMINUM	MFG
0103004-101	TILT PLATFORM SUPPORT	1	32	ALUMINUM	MFG
N/A	4-40 X .312 FLATHEAD SCREW	9	33	STEEL	COML
0103008-101	GEAR SHAFT ASSY	1	60		
0103005-101	RECTANGULAR SHAFT	2	34		MFG
0103005-103	RECTANGULAR SHAFT	1	35	ACRYLIC	MFG
0103005-105	RECTANGULAR SHAFT	1	36	ACRYLIC	MFG
0103006-101	GEAR, 40 TOOTH	1	37	ACRYLIC	MFG

0103007-101	UPPER SHAFT COLLAR	1	38	ACRYLIC	MFG
0103007-103	LOWER SHAFT COLLAR	1	39	ACRYLIC	MFG
N/A	4-40 X .25 SCREW	2	40	STEEL	COML
638150	ELECTRIC MOTOR	1	48		servocity
N/A	SCREW	4	49	STEEL	COML
615270	PINION GEAR, 32 TOOTH	1	50	BRASS	servocity
N/A	SET SCREW	1	51	STEEL	COML
0106000-101	TILTING PLATFORM ASSY	1	41		MFG
0106001-101	TILTING PLATFORM	1	42	ALUMINUM	MFG
0106002-101	ROTATION BLOCK	3	43	ALUMINUM	MFG
0106003-101	RELEASE LEVER	1	47	PLASTIC	MFG
N/A	6-32 X .75 FLATHEAD SCREW	6	44	STEEL	COML
N/A	4-40 X .25 SET SCREW	3	45	STEEL	COML
N/A	CAMERA MOUNT ASSY	1	46		DMKFoto
N/A	3/8-16 X .5 FLATHEAD BOLT	1	47	STEEL	COML
0104000-101	ELECTRONICS PACKAGE	1	52		
N/A	ARDUINO DIG CONTROLLER	1	53		COML
0104001-101	CIRCUIT BOARD	1	54		MFG
N/A	BATTERY, RECHARGABLE	1	55		
N/A	JOYSTICK/W CIRCUITBOARD	1	61		COML
N/A	6-32 X .375 SCREW	2	62	STEEL	COML
N/A	6-32 NUT	2	63	STEEL	COML
N/A	SPST SWITCH	1	64		COML
N/A	WIRE	A/R	65		COML
0105000-101	GEAR SHAFT ASSY	1	56		MFG
0105001-101	SHAFT	1	57	STEEL	MFG
615270	PINION GEAR, 32 TOOTH	1	58	BRASS	servocity
N/A	6-32 X .375 SCREW	4	66	STEEL	COML
N/A	6-32 NUT	4	67	STEEL	COML
N/A	NO. 6 WASHER	4	68	STEEL	COML
N/A	6-32 X .375 FLATHEAD SCREW	4	69	STEEL	COML
N/A	6-32 NUT	4	70	STEEL	COML
N/A	NO. 6 WASHER	4	71	STEEL	COML

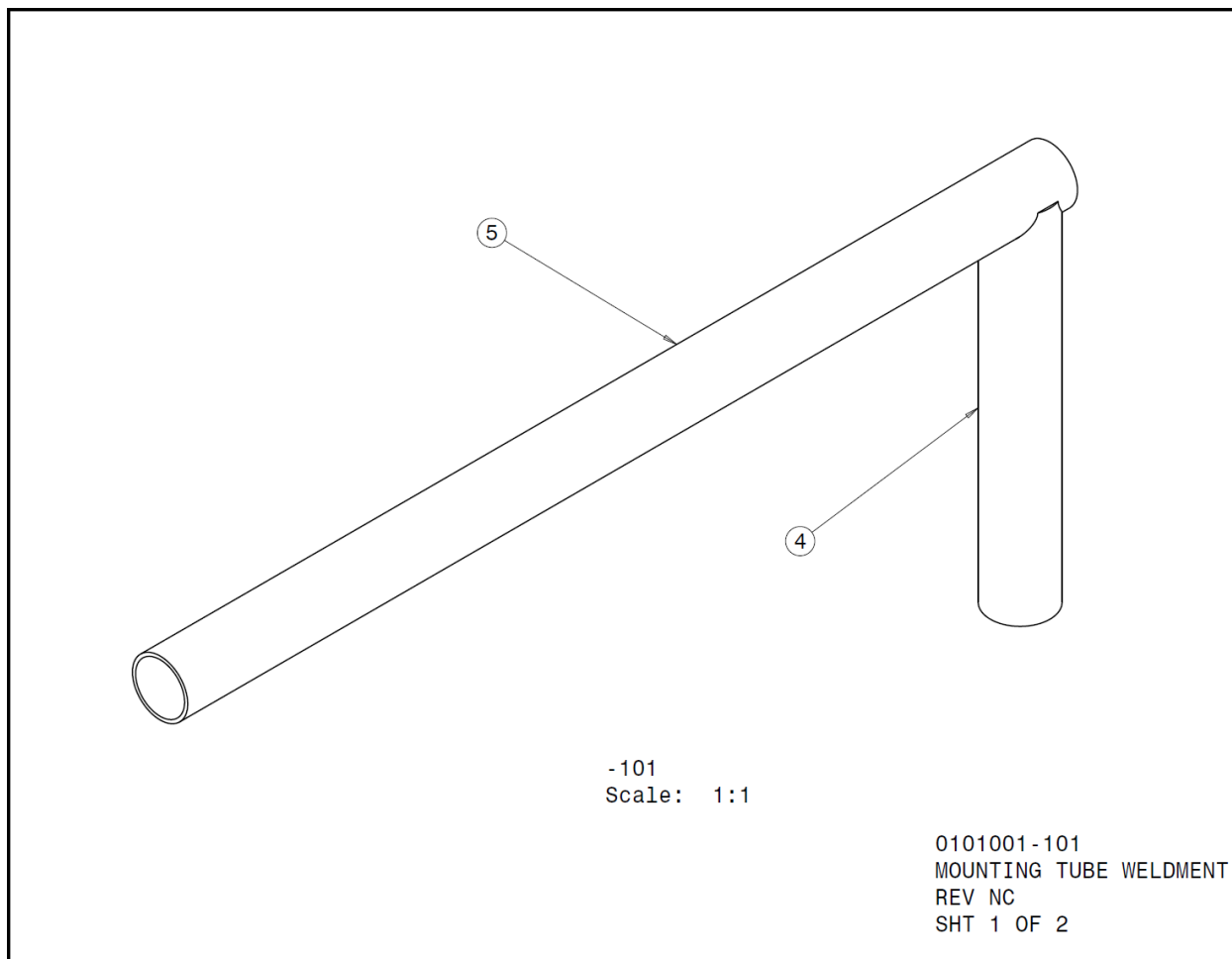
Appendix D – Drawings

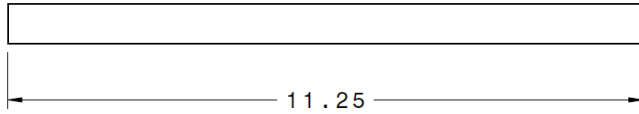




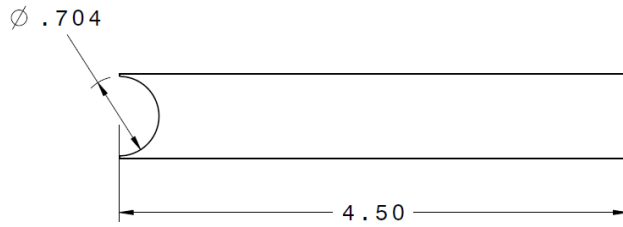
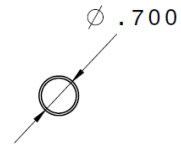
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0101000
MOUNTING ASSY
REV NC

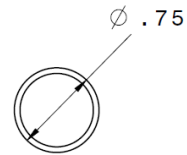




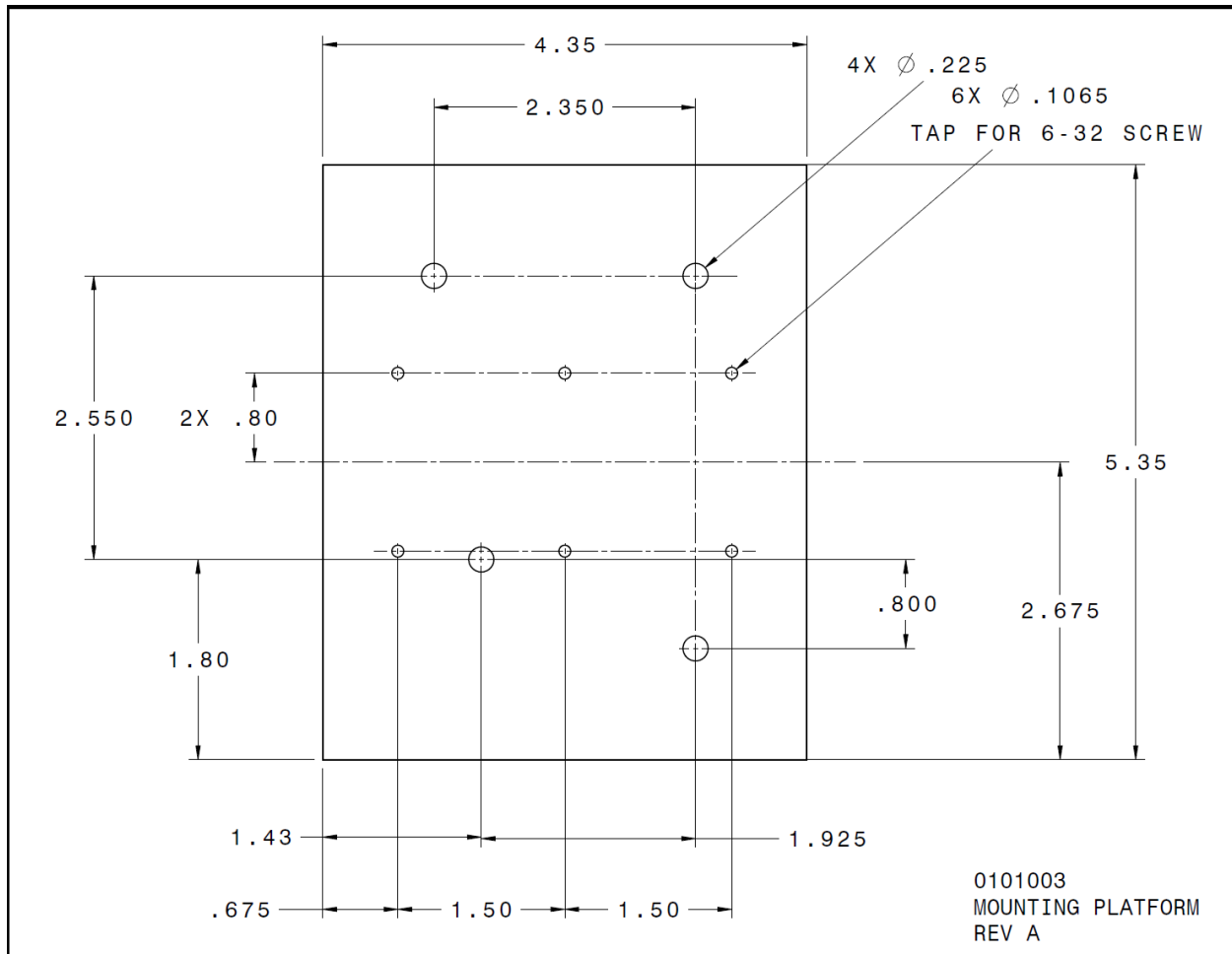
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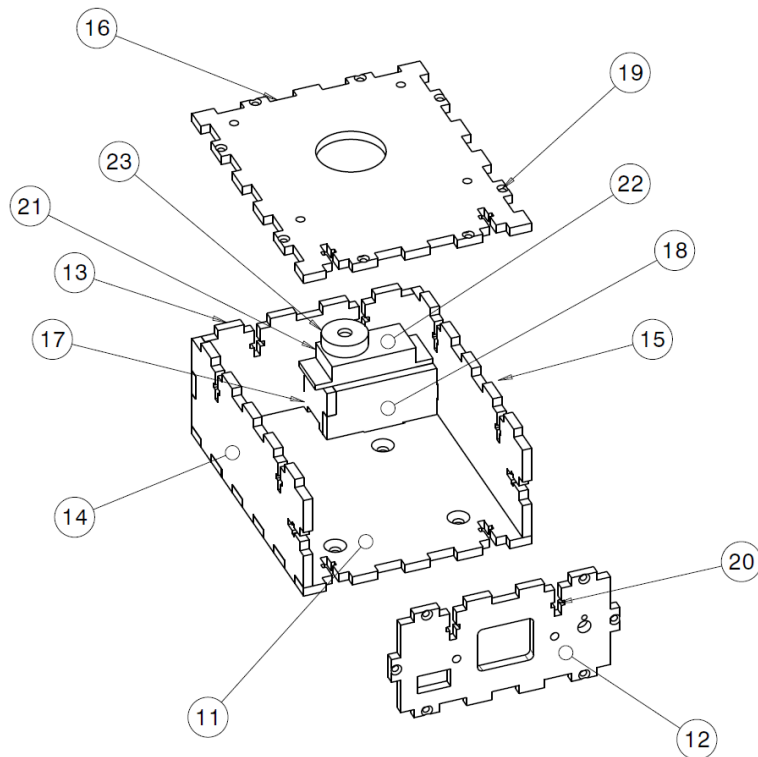


-201
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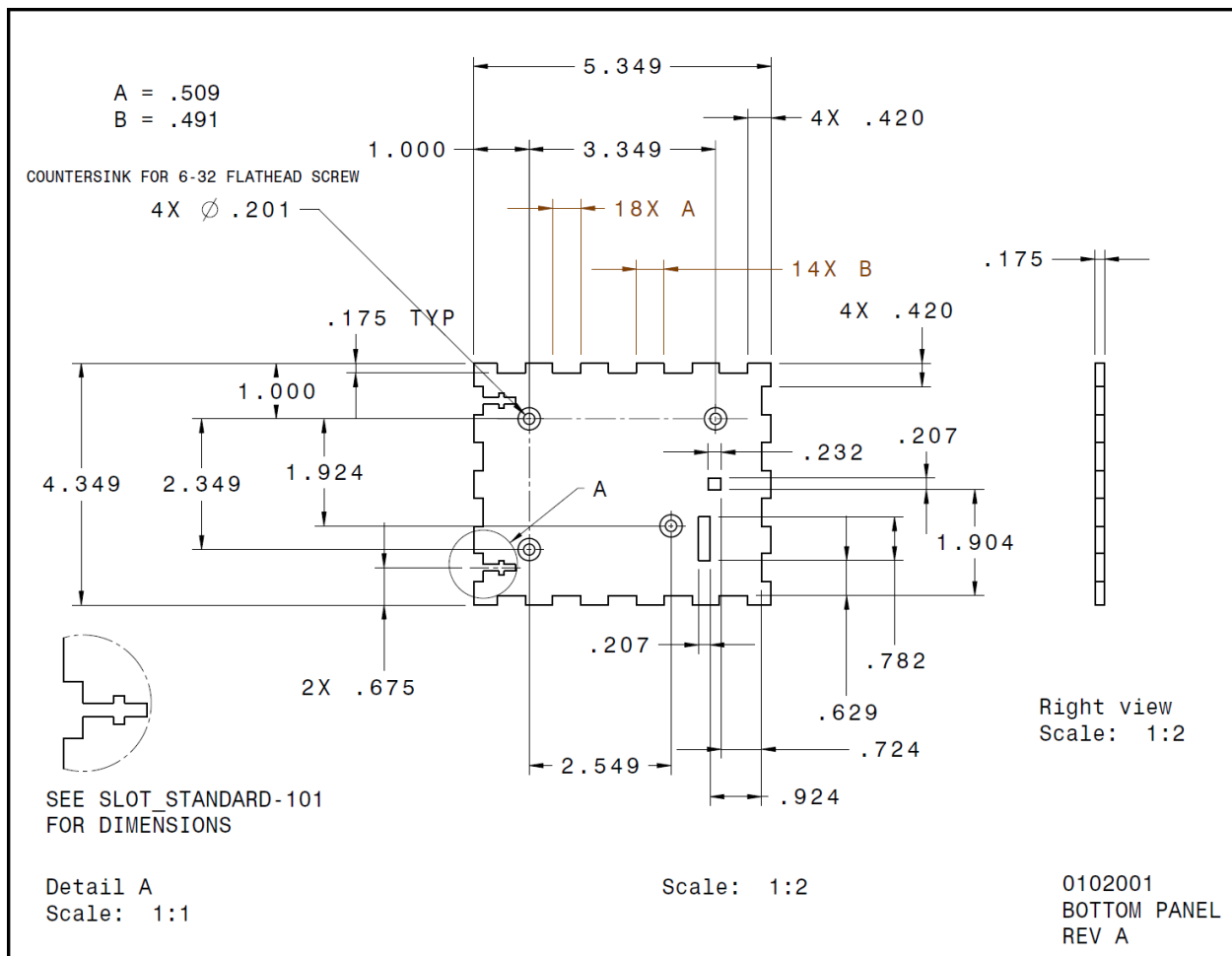
0101001
MOUNTING TUBE WELDMENT
REV NC
SHT 2 OF 2

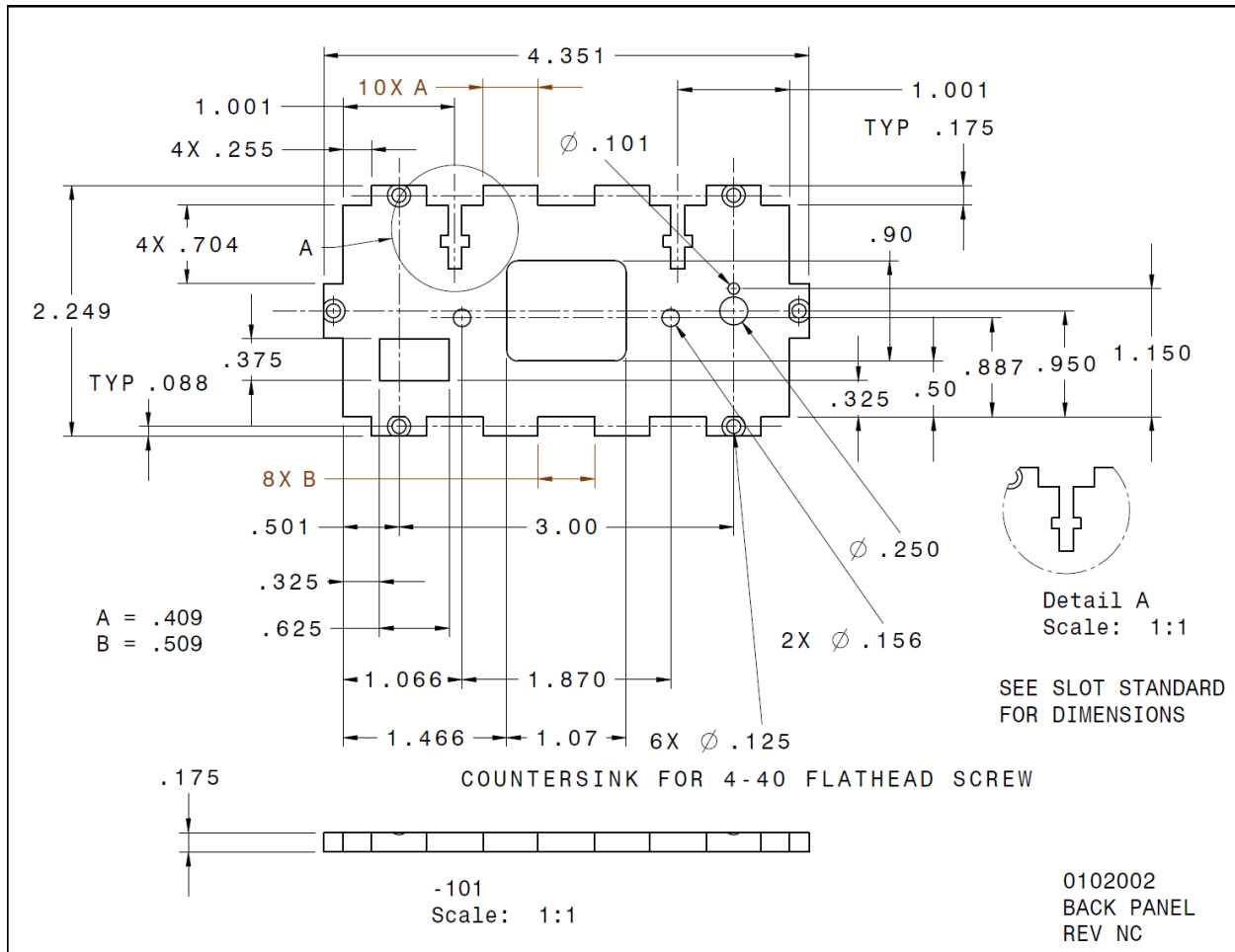


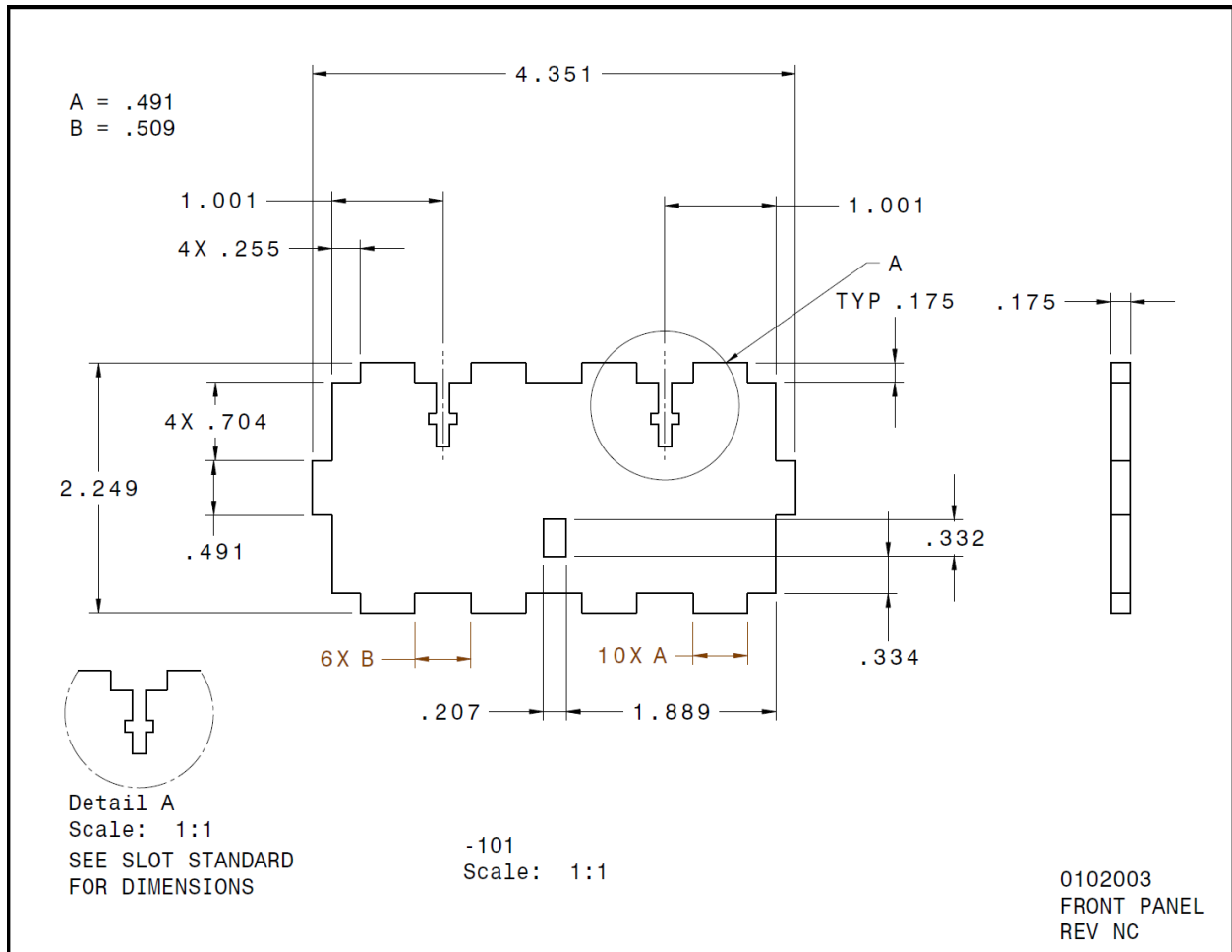


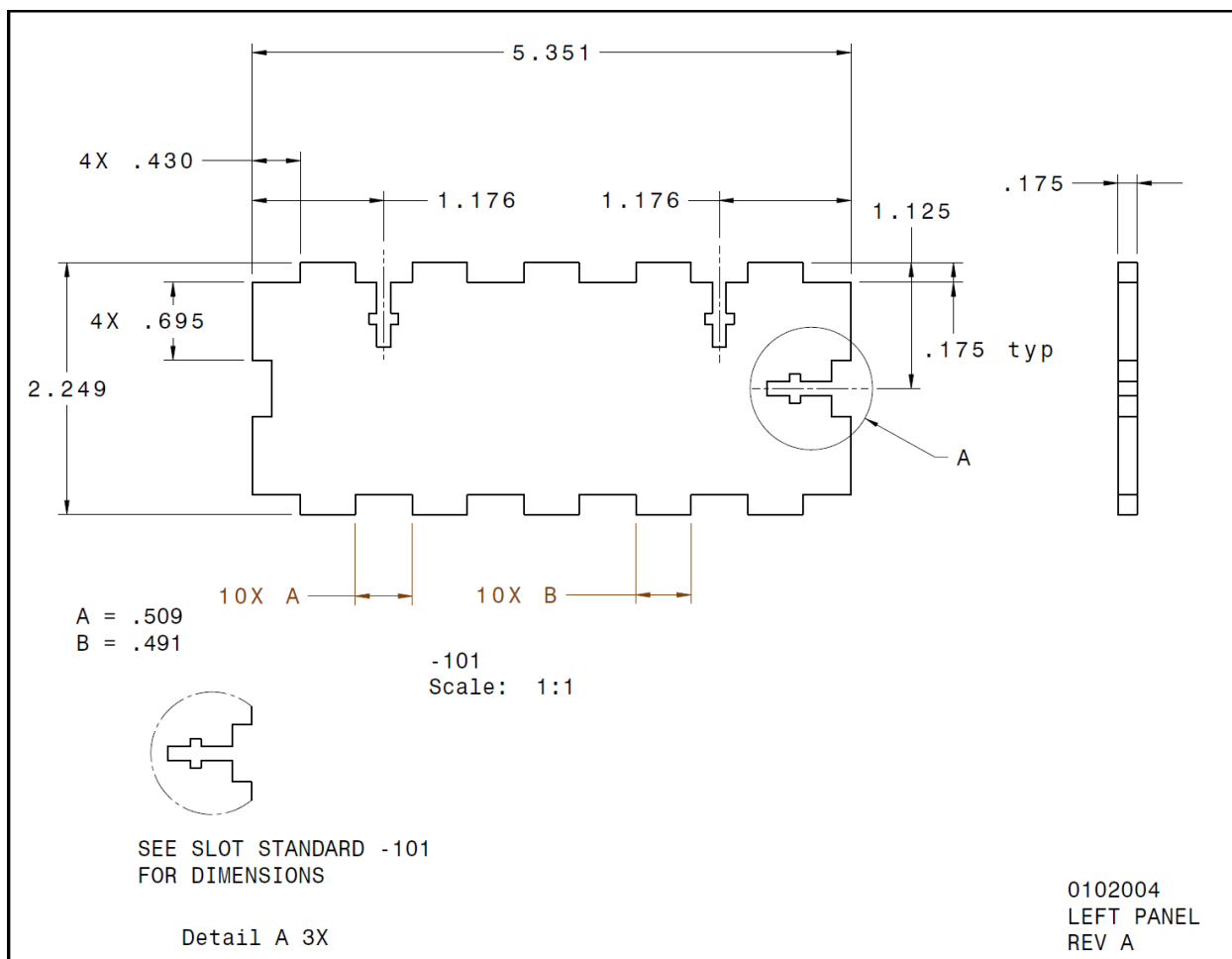
-101
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0102001
ENCLOSURE ASSY
REV NC

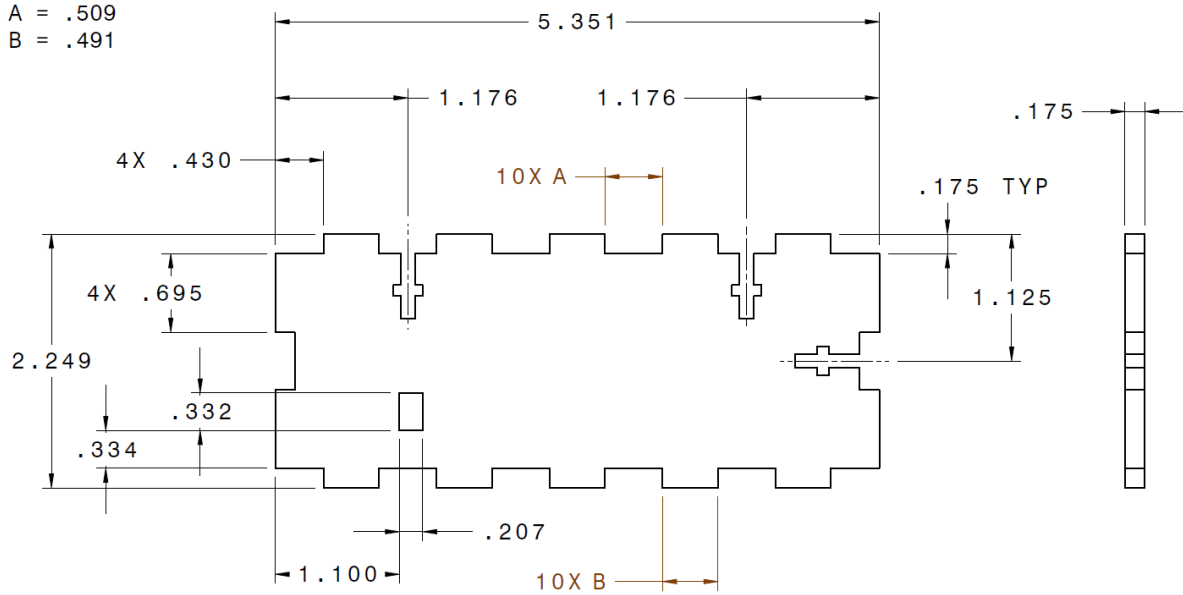






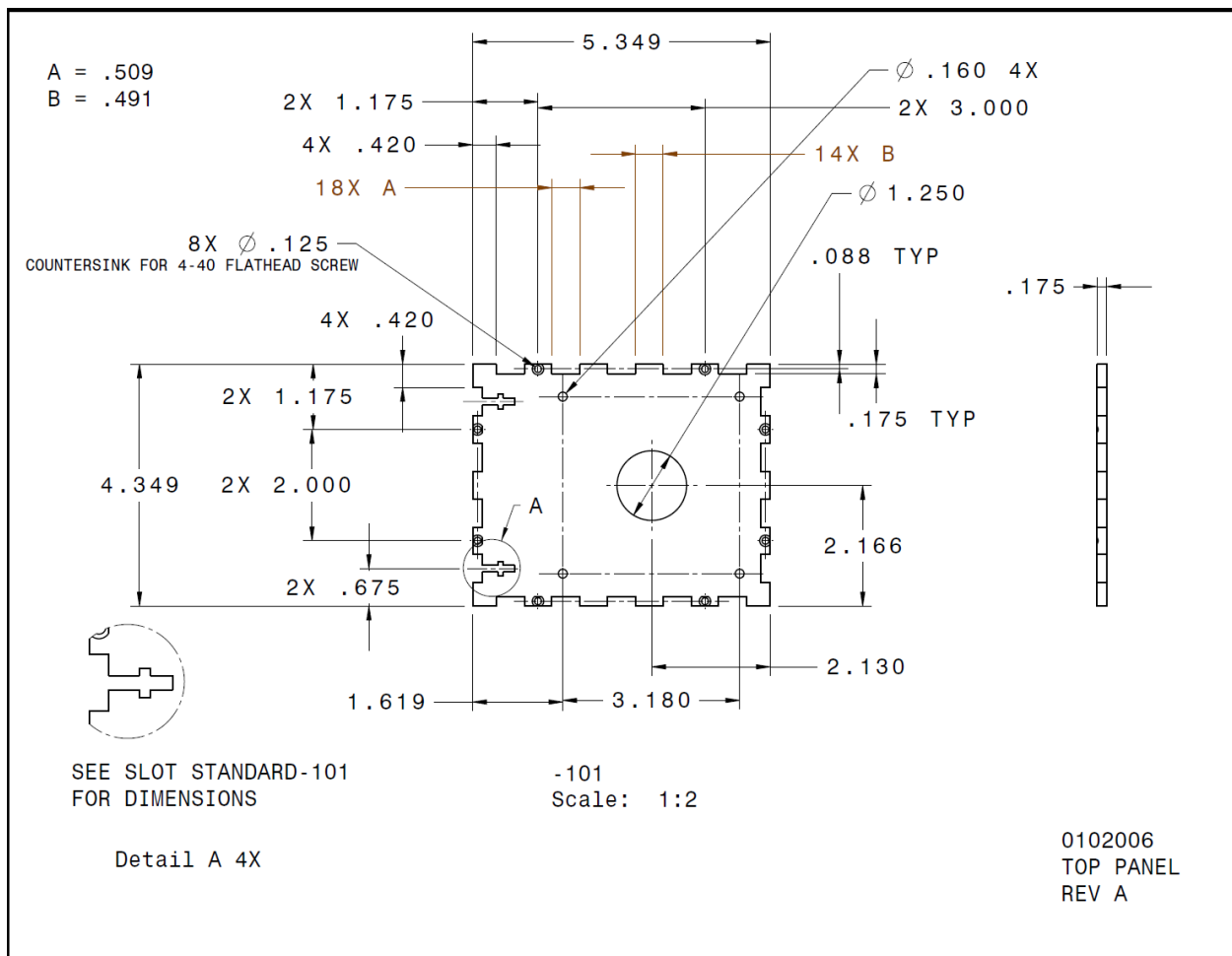


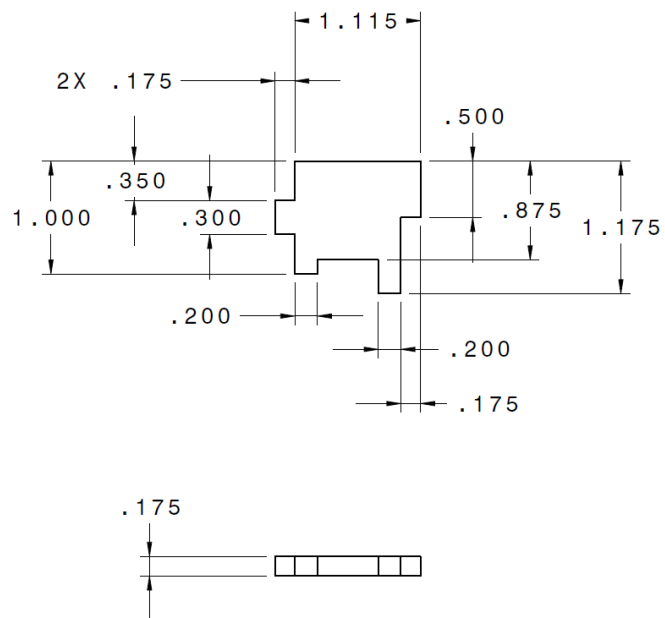
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B = .491



-101
Scale: 1:1

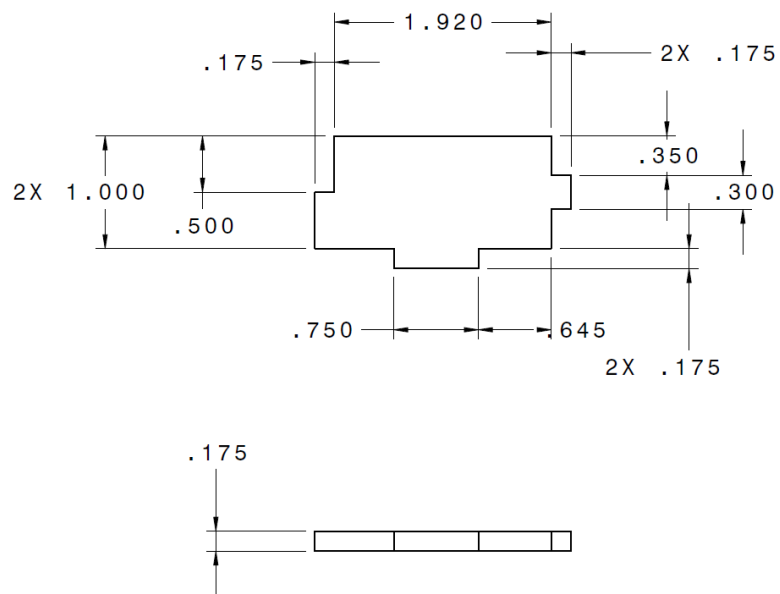
0102005
RIGHT PANEL
REV A





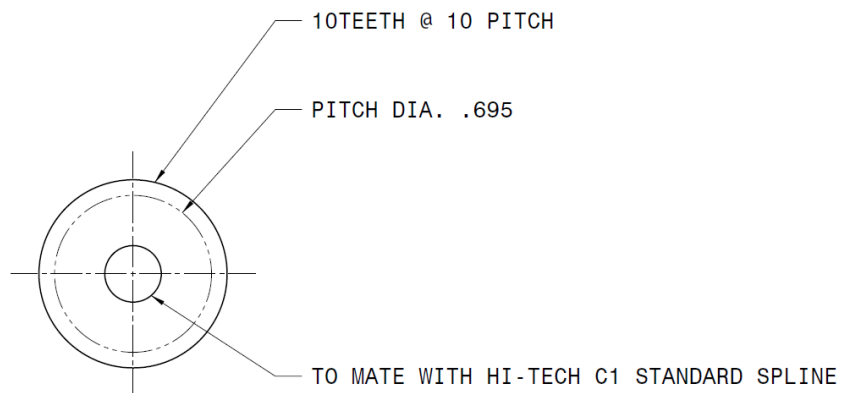
-101
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0102007
SERVO PANEL
REV A



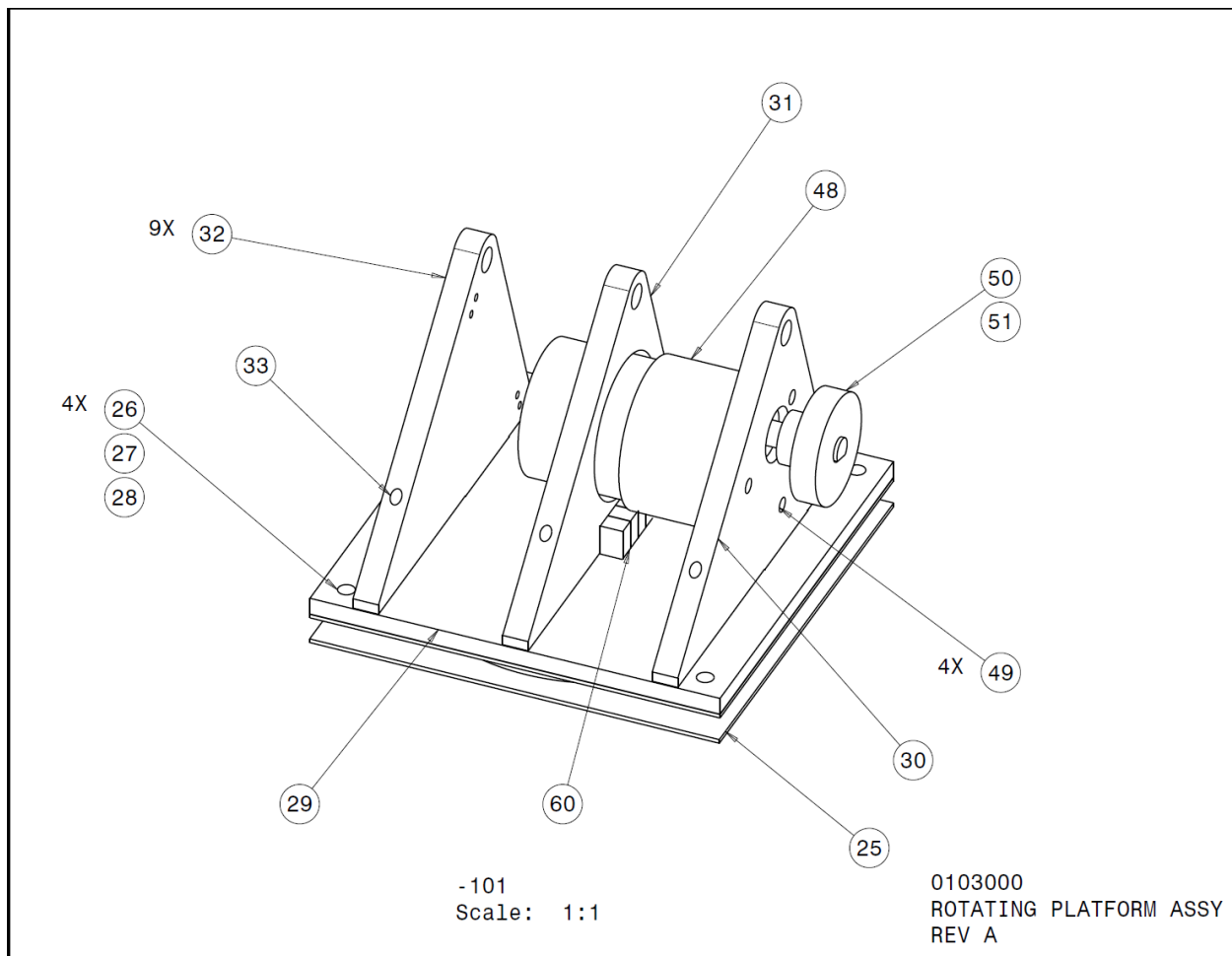
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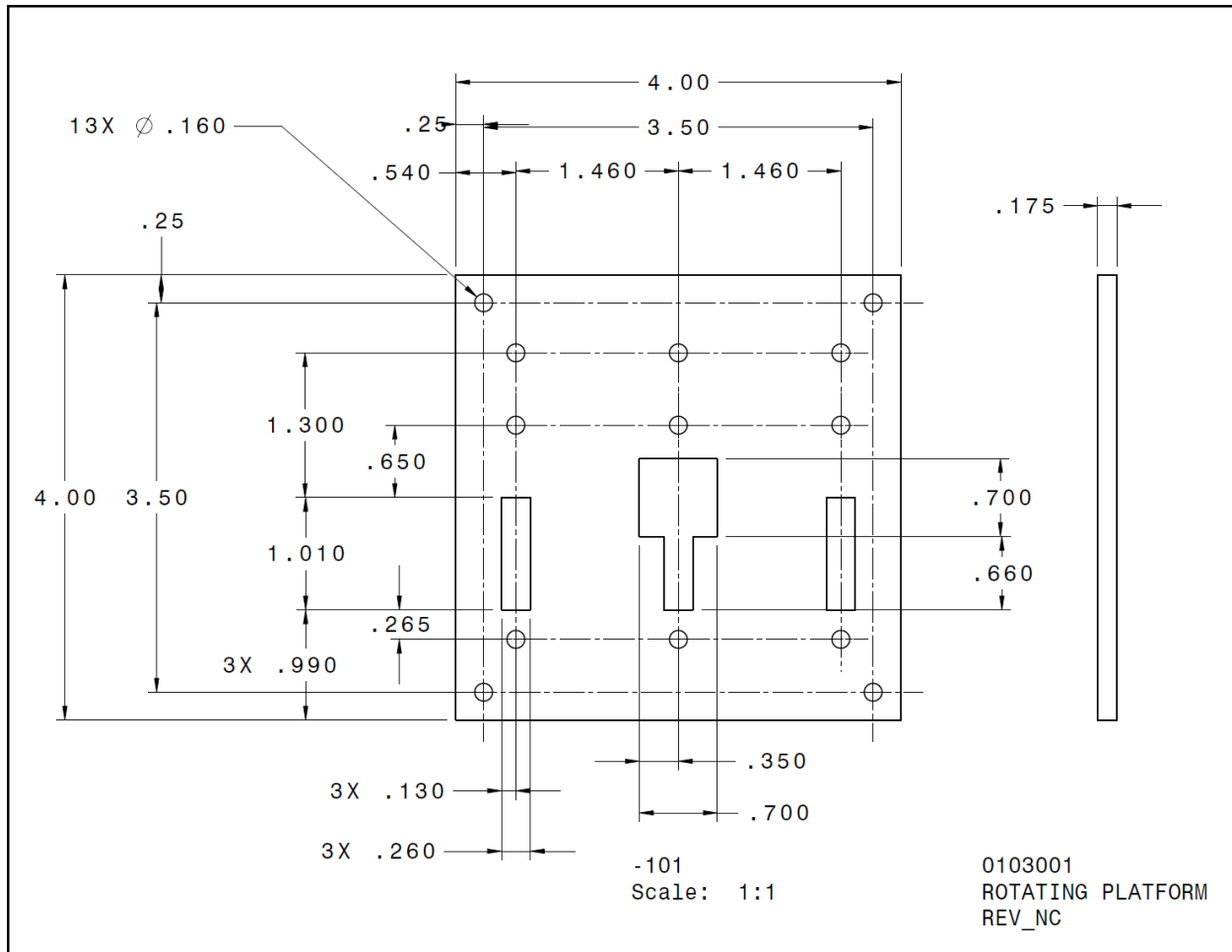
0102008
SERVO PANEL
REV A

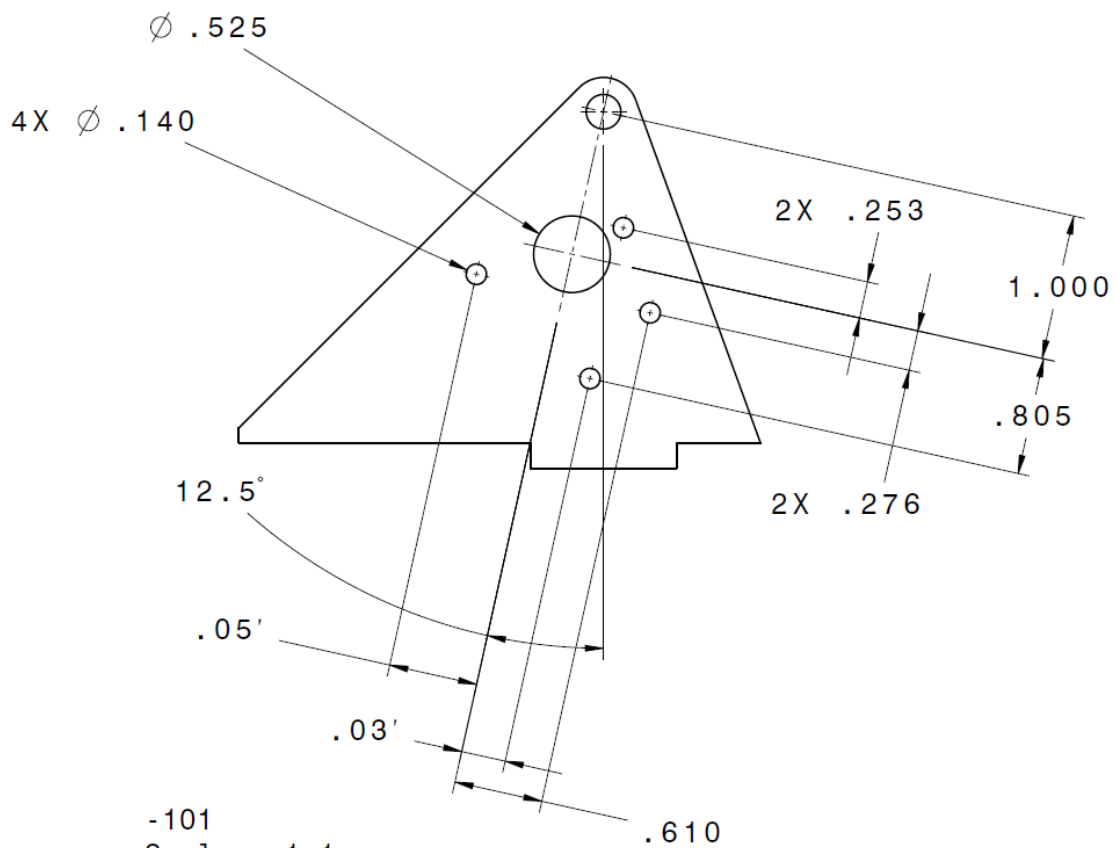


-101
Scale: 2:1

0102010
10 TOOTH GEAR
REV A





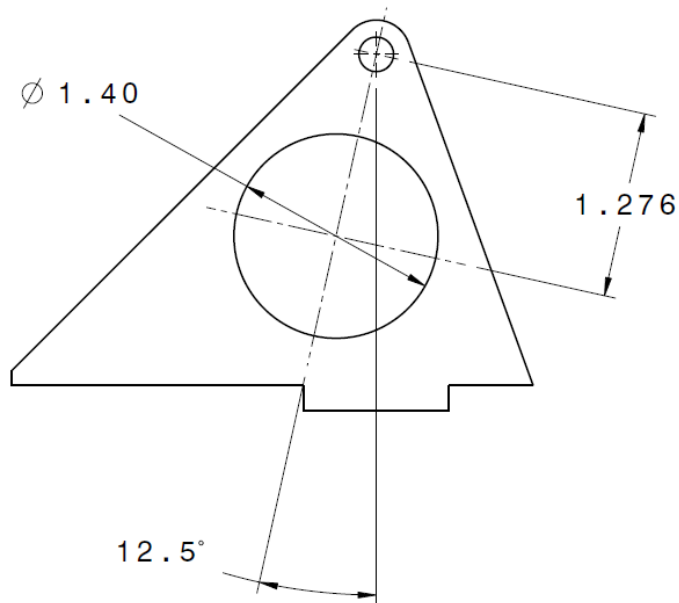


ALL DIMENSIONS NOT SHOWN ARE IDENTICAL TO 0103003-101



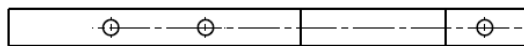
Bottom view
Scale: 1:1

0103002
TILT PLATFORM SUPPORT
REV A



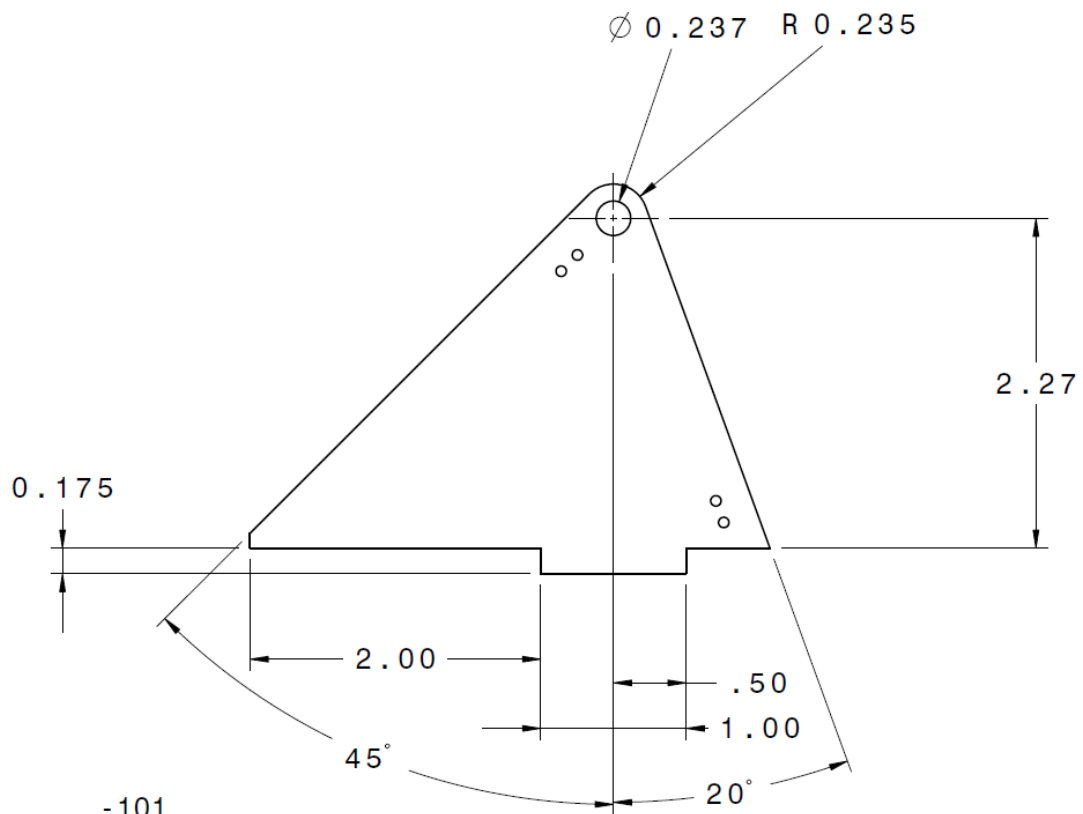
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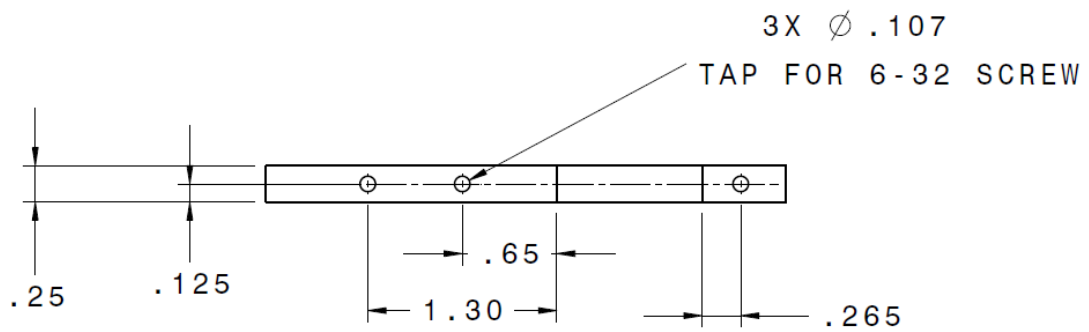


Bottom view
Scale: 1:1

0103003
PLATFORM SUPPORT
REV A

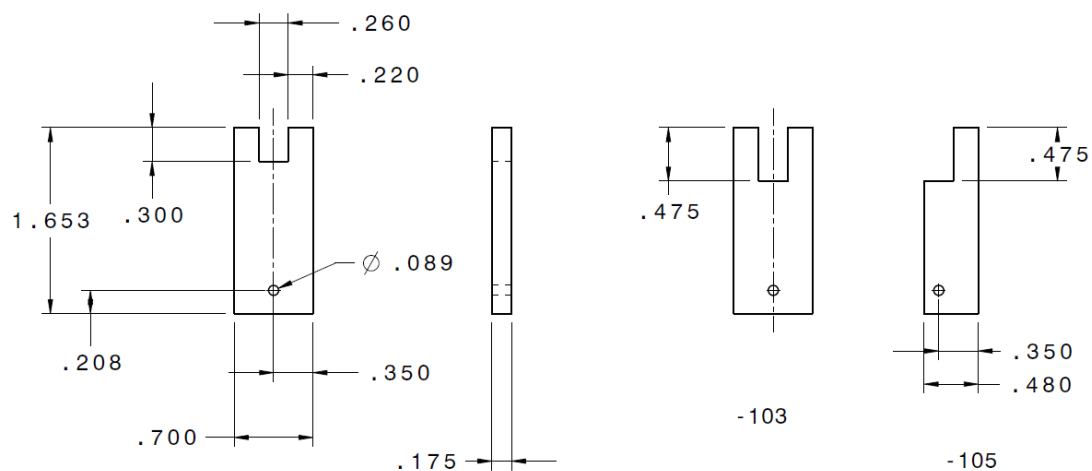


-101
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Bottom view
Scale: 1:1

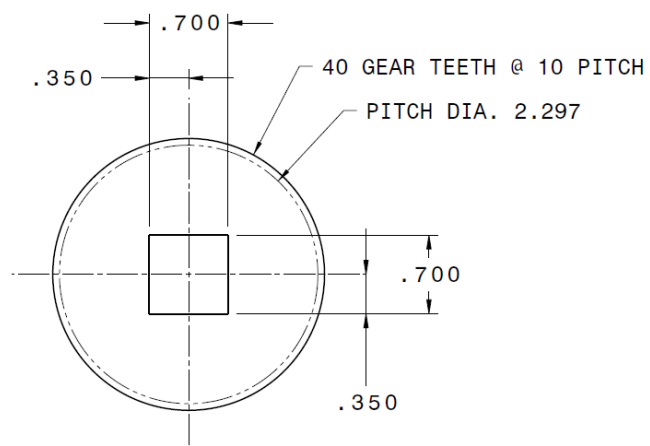
0103004
PLATFORM SUPPORT
REV A



-101
SCALE: 1:1

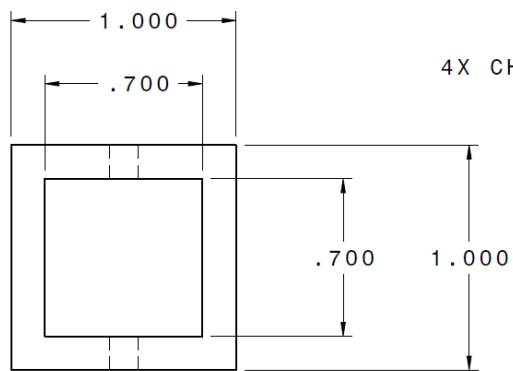
DIMENSIONS NOT SHOWN ARE IDENTICAL TO -101

0103005
RECTANGULAR SHAFT
REV A

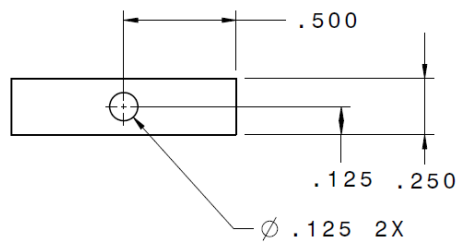
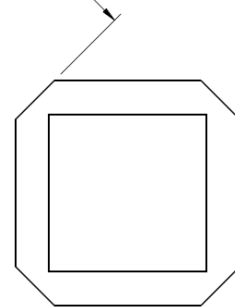


-101
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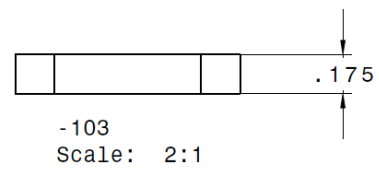
0103006-101
40 TOOTH GEAR
REV A



4X CHAMFER .175 X .175



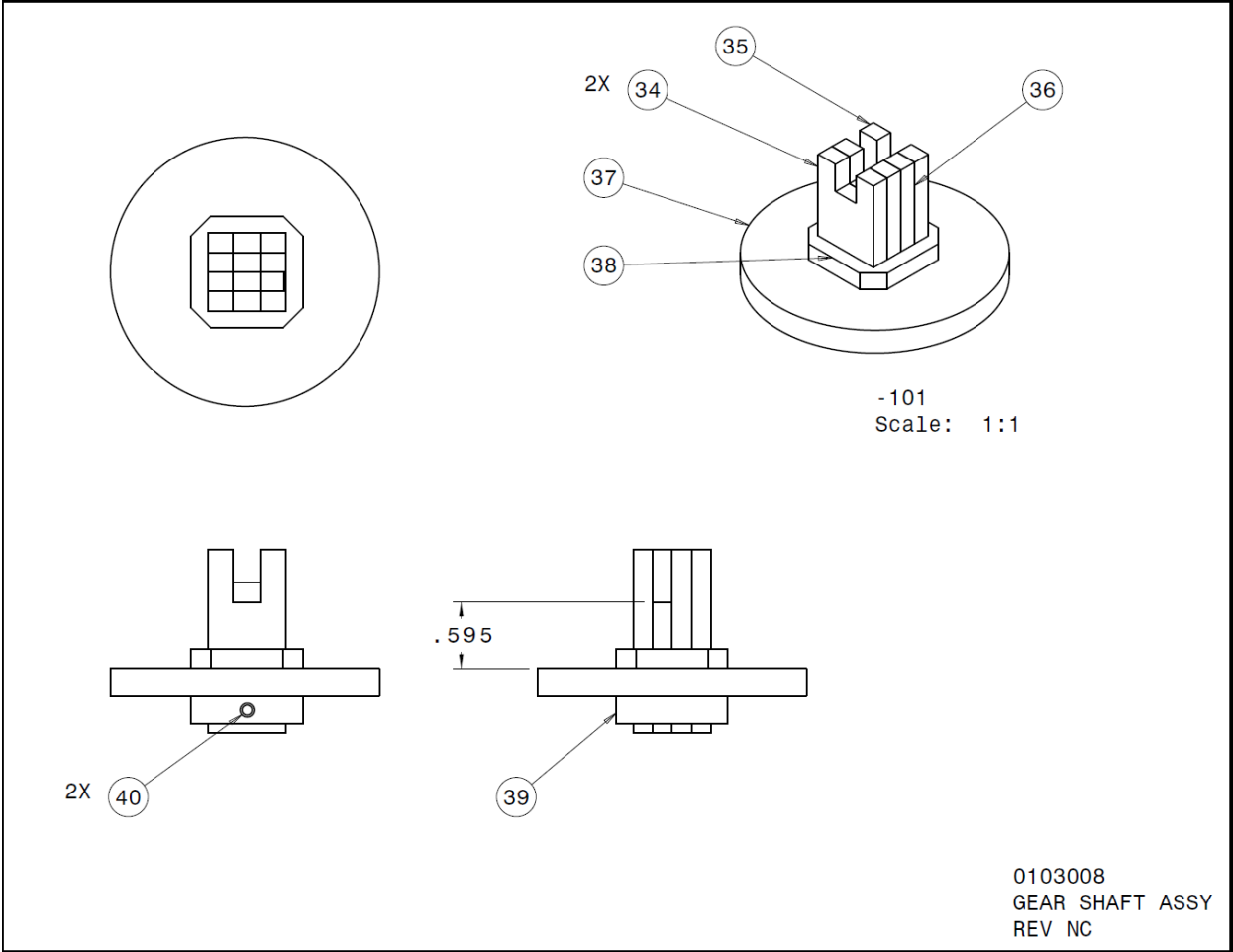
-101
Scale: 2:1

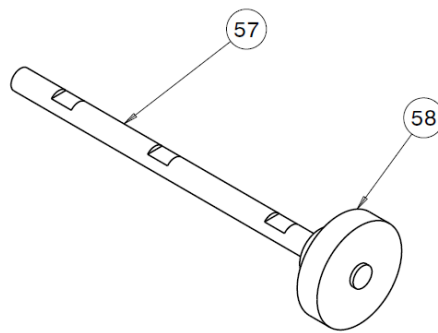


-103
Scale: 2:1

ALL DIMENSIONS NOT SHOWN ARE IDENTICAL TO -101

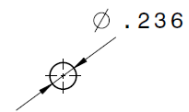
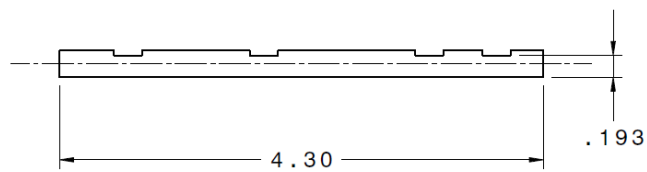
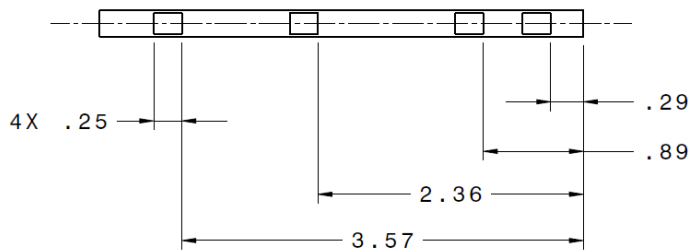
0103007
GEAR COLLARS
REV A





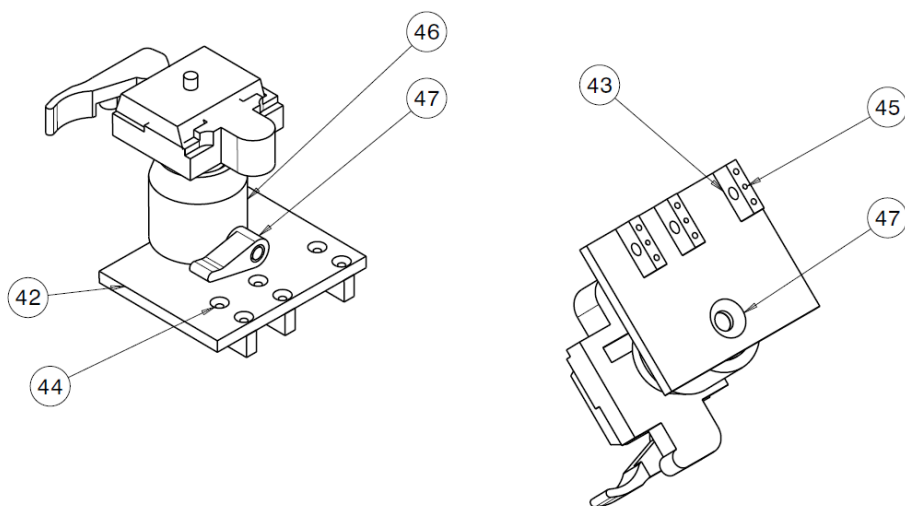
-101
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0105000
GEAR SHAFT ASSY
REV NC



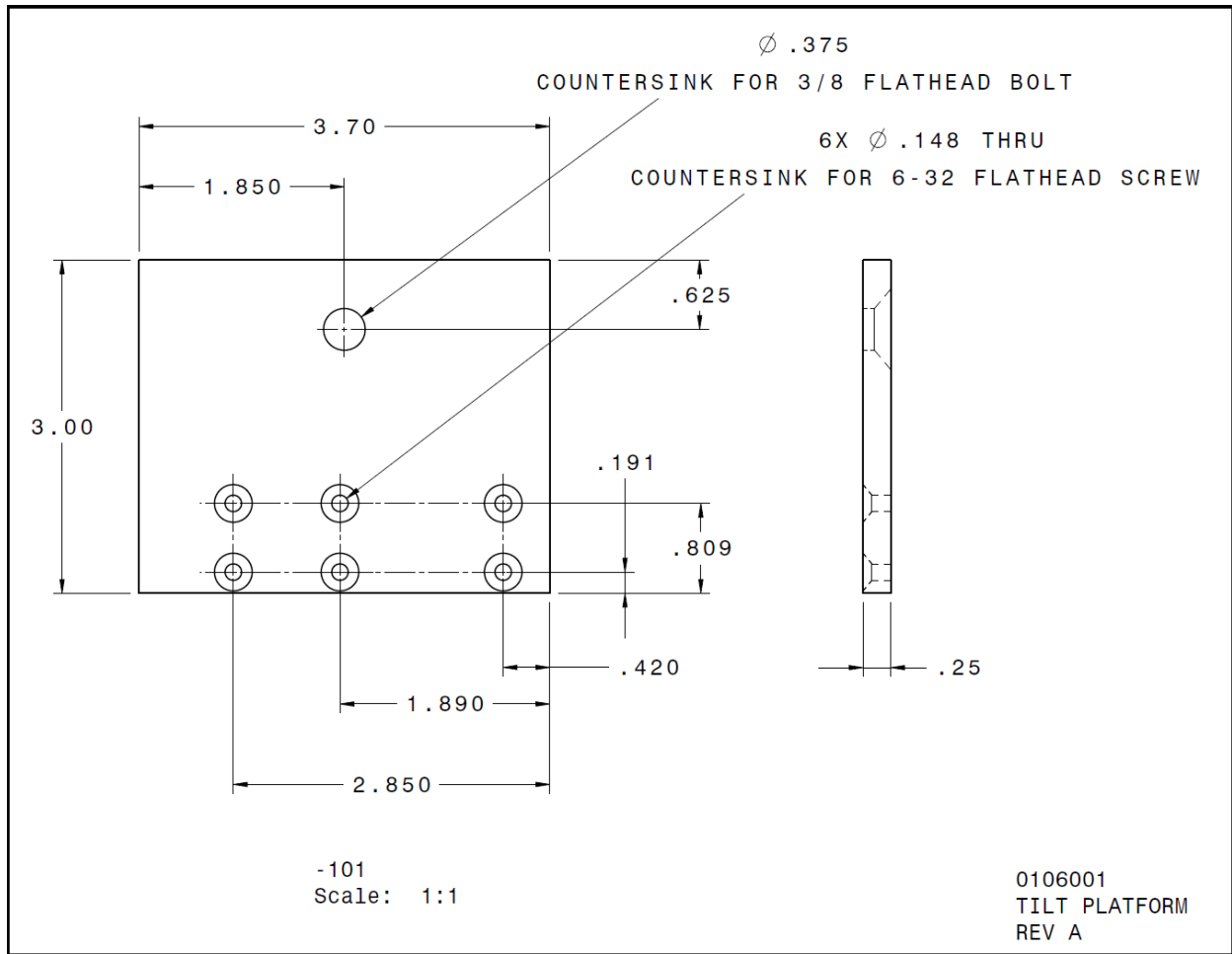
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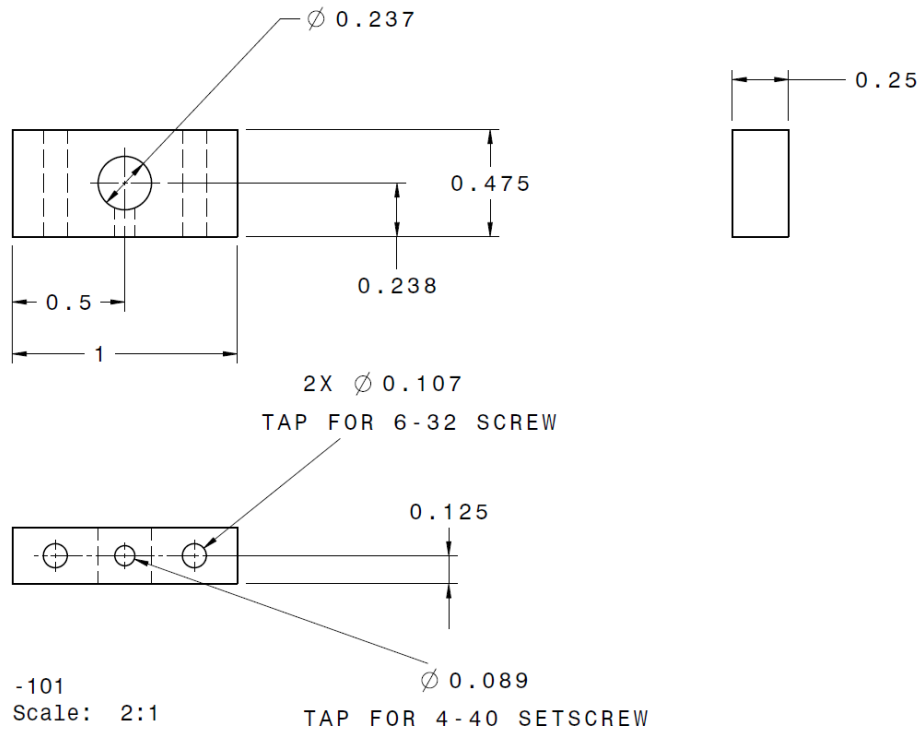
0105001
SHAFT
REV NC



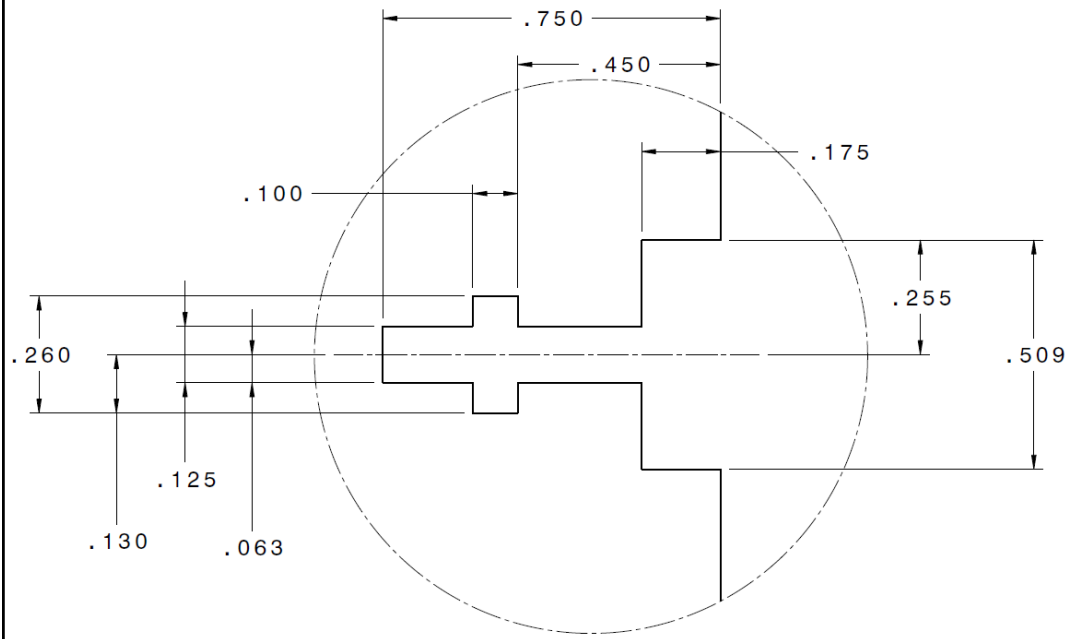
-101
Scale: 1:2

0106000
TILT PLATFORM ASSY
REV NC





0106002
ROTATION BLOCK
REV A



-101
Scale: 4:1

FASTENER_SLOT
REV NC